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THESIS

THERMISTOR VALIDATION AND PATH RADIANCE
EFFECTS IN SHIP THERMAL IMAGE MEASUREMENTS

by

David S. Wood

September, 1991

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THERMISTOR VALIDATION AND PATH RADIANCE EFFECTS IN SHIP THERMAL IMAGE MEASUREMENTS

by

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Captain, United States Marine Corps
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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING
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ABSTRACT

Thermal images in the 8 - 12 μm band were taken of the research vessel R/V POINT SUR in the Monterey Bay on 7 May 1991. The images were recorded using the AGA Thermovision 780 with an IBM AT computer using CATS 2.1 software. Corrections for computed transmittance, path length, and emissivity were made to the image files utilizing the locally developed computer program AGACATS. Temperature measurement distributions made with the AGA 780 compared to thermistor measurements of the ship temperatures were found to be extremely close (within one degree) at ranges of one half mile and one mile. PC-TRAN in the radiance mode was than used to compute the path radiance to the ship and compared with the path radiance correction in the AGA 780 algorithm. The AGA measurements varied over the range from twenty-five to seventy-five percent while the LOWTRAN fraction ranges only from seventy-five to eighty-five percent with the biggest discrepancy occurring at the short paths. The predicted path radiance as computed using LOWTRAN 6 did not fall off as much with decreased slant range as the AGA path radiances. This difference may be attributed to problems with either the AGA algorithm or the LOWTRAN code, or with the accuracy of the inputs. A contributing factor may be the time delay of one to one and a half hours between the image data and the radiosonde balloon launch.

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I. INTRODUCTION

Forward Looking Infrared (FLIR) technology is utilized on a daily basis by Navy/Marine tactical aircraft. FLIR systems are currently employed by military planners in the detection, identification and recognition of targets of tactical importance. A commander needs to know the standoff ranges at which an enemy can detect a ship using passive infrared (IR) sensors so that an estimate can be made of the time needed to perform countermeasures against weapons that are launched.

The performance of many military systems using FLIR technology is highly reliant on environmental conditions in the area of tactical operation (Figure 1.1).[Ref. 1]

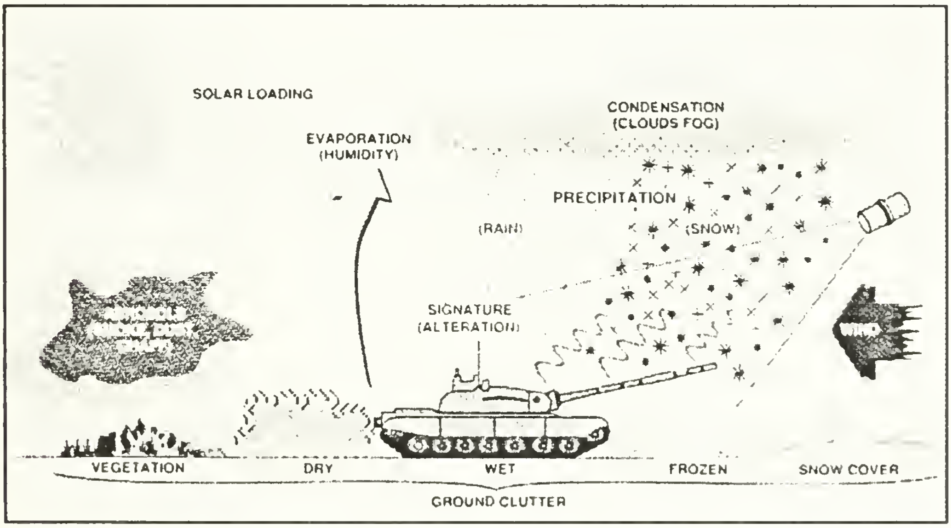

Figure 1.1 Environmental Effects on IR [Ref. 1]

These systems can have their effectiveness seriously degraded by atmospheric conditions such as precipitation, snow, clouds,

and aerosols due to absorption, scattering, refraction, and reflection of the infrared (IR) energy along the transmission path (Figure 1.2).

WEATHER PARAMETERS	VISIBLE AND NEAR IR	SHORTWAVE IR	MIDWAVE IR	LONG WAVE IR	MMW
LOW VISIBILITY	SEVERE	MODERATE	LOW	LOW	NONE
RAIN/ SNOW	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE/ LOW
HIGH HUMIDITY	LOW	LOW	MODERATE	MODERATE	LOW/NONE
FOG/ CLOUD	SEVERE	SEVERE	MODERATE/ SEVERE	MODERATE/ SEVERE	MODERATE/ LOW
PHOSPHORUS/ DUST	SEVERE	SEVERE/ MODERATE	MODERATE	MODERATE	LOW/ NONE
FOG OIL/ SMOKE	SEVERE	MODERATE	LOW	LOW	NONE

Figure 1.2 Effects of Weather on IR at Different Wavelengths [Ref. 1]

In order to achieve the best possible performance for a FLIR system, Tactical Decision Aid (TDA) computer codes have been developed which are based on target and background characteristics and atmospheric conditions as well as FLIR parameters. Estimates of FLIR system performance against a target are frequently based on an assumed temperature difference between a target and its background. Computational algorithms are applied to determine the range at which the assumed temperature difference is lowered by the atmospheric IR transmittance to the minimum detectable temperature difference (MDTD) of the sensor system. This technique disregards the consequences of sky radiance reflections and

the atmospheric path emission contributions to the entire background scene which change with viewing angle and altitude of the sensor.

Mission planners and on-scene commanders use the Updated FLIR (UFLIR) prediction model which is a function of the Tactical Environmental Support System (TESS). UFLIR is an atmospheric computer program which provides expected ranges with a 50% probability to detect, categorize, and identify targets utilizing airborne FLIR sensors. The infrared sensors act as electronic cameras which image targets (ships, submarines, vehicles, etc.) by intercepting the excess IR radiation they emit as a result of being warmer then the surrounding environment. A sensor's capability of detecting or recognizing a target is dependent upon the image contrast. The image contrast is the difference between the target and background emittance. When a target is viewed against a uniform background of identical temperature, as in the case of a vehicle which has not moved in several days, it will be less easily detectable. The most advanced military IR sensors can detect temperature differences of less than one degree celsius and are extremely effective in detecting targets at night.

II. THEORY AND BACKGROUND

The purpose of this chapter is to give the reader a fundamental understanding of IR radiation and its relationship to the electromagnetic spectrum. This chapter will also review the terminology and equations upon which the study of IR radiation is founded.

A. THE INFRARED (IR) SPECTRUM

IR radiation is a small segment of the total electromagnetic spectrum which includes other forms of radiation (radio waves, X-rays, visible light, etc.) which are organized into bands or ranges according to wavelength or frequency as shown in Figure 2.1 [Ref. 2:p. 20].

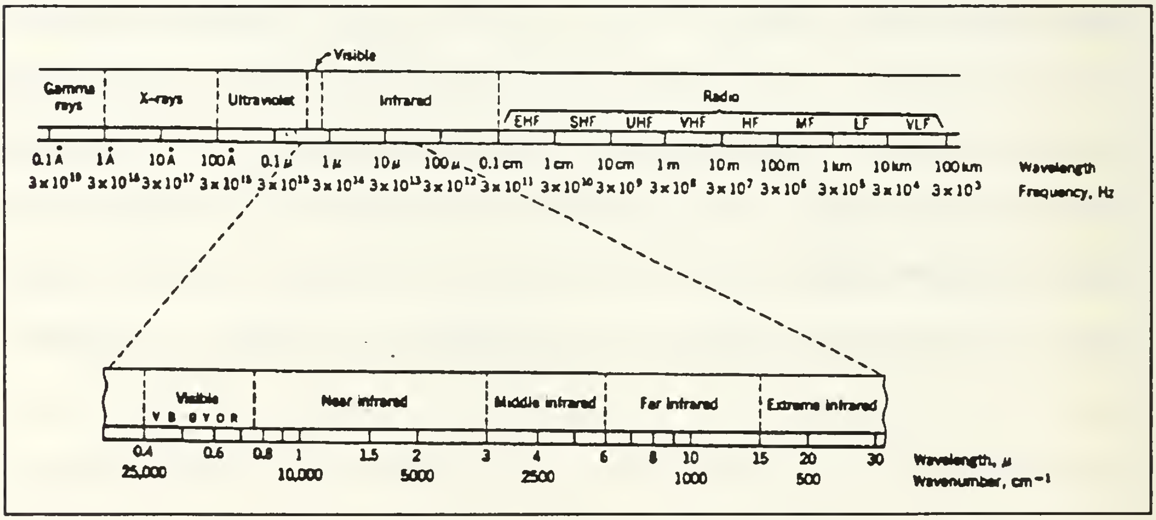

Figure 2.1 Electromagnetic Spectrum [Ref. 2]

The wavelength and frequency are related by the equation:

$$c=f\lambda \tag{1}$$

where c is the speed of light in meters per second, f is the frequency in Hertz, and λ is the wavelength in meters.
The IR band comprises the wavelength range from 0.75×10^{-6}[m] to 1.00×10^{-3}[m] or the frequency range from 3.00×10^{11}[Hz] to 4×10^{14}[Hz] and is divided into three regions - near, middle, and far infrared. Because IR radiation is a part of the electromagnetic spectrum, it will "obey the laws of reflection, refraction, diffraction, and polarization". [Ref. 2:p. 20]

B. THERMAL RADIATION

In order to discuss the different quantities associated with IR radiation, an understanding of the vocabulary, terms, and laws must be conveyed. The equations and definitions for this section were primarily taken from Hudson [Ref. 2:p. 35-64], notes from Dr. Cooper [Ref. 3] and Lloyd [Ref. 4].

1. Blackbody Radiation and IR (Planck's Law)

All objects that are at temperatures above absolute zero radiate IR energy into the electromagnetic spectrum. The amount of energy emitted is dependent upon the size and temperature of the object and the wavelength. The spectral radiant emittance is the radiant power emitted per unit area

of a source per unit wavelength interval ($W_\lambda[Wcm^{-2}\mu m^{-1}]$). A benchmark used as the best radiator of IR energy is defined as a "blackbody". A blackbody theoretically emits and absorbs the greatest possible amount of thermal radiation at any given temperature, radiates at all wavelengths, and is perfectly diffuse. The spectral radiant emittance from a blackbody is given by Planck's Law:

$$W_\lambda=\left(\frac{2\pi hc^2}{\lambda^5}\right)\left(\frac{1}{e^{ch/\lambda kT}-1}\right)\left[\frac{watts}{cm^2\mu m}\right] \qquad (2)$$

where:

λ = wavelength [m]

k = Boltzmann's constant

= 1.38054×10^{-23} [W sec/ K]

h = Planck's constant

= 6.6256×10^{-34} [W sec^2]

T = temperature (K)

Planck's Law is fundamental to all FLIR systems and is valid for the entire electromagnetic spectrum. This equation is graphically expressed for several temperatures in Figure 2.2.

2. Stefan-Boltzmann Law

Integrating Planck's Law yields the radiant emittance for a blackbody source over a spectral band as shown in the following equation:

$$W=\int_{\lambda_1}^{\lambda_2} W_\lambda d\lambda \qquad (3)$$

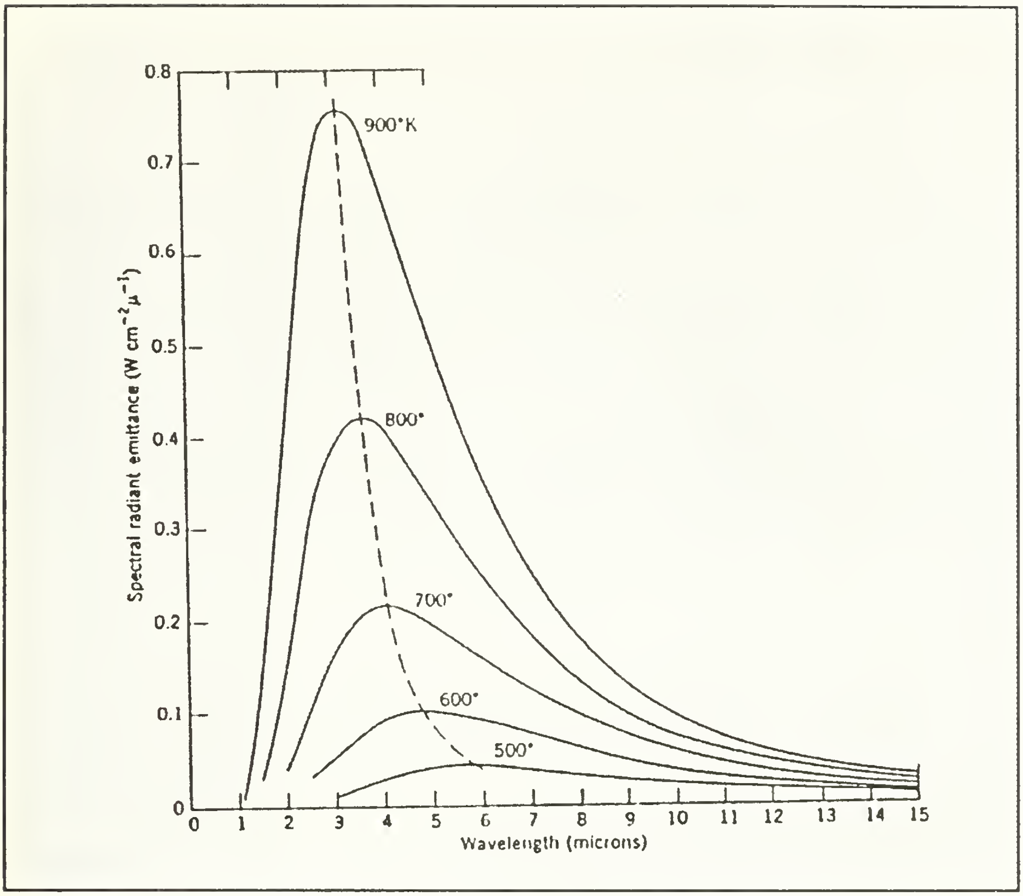

Figure 2.2 Spectral Radiant Emittance [Ref. 2]

where W_λ is the spectral radiant emittance while λ_1 and λ_2 are the spectral band boundaries. The Stefan-Boltzman Law is then derived by performing the above integration over the wavelength interval of zero to infinity resulting in:

$$W=\sigma T^4 \qquad (4)$$

where:

W = the radiant emittance in [W/cm^2]

σ = Stefan-Boltzman constant

= 5.6697 x 10^{-12}[W/cm^2 K]

T = temperature in Kelvin (K)

From the above expression the total radiant emittance of a blackbody source for all wavelengths can then be found.

3. Emissivity of an Object

The emissivity (ϵ) of an object is the ratio of the radiant emittance of the target or source to the radiant emittance of a blackbody at the same temperature. Most objects within our surroundings emit only a fraction, which is known as "emissivity", of blackbody radiant power. The values of emissivity are in the range of zero to one with one being a blackbody (Figure 2.3). Therefore the Stefan-Boltzmann law is written as follows:

$$W=\epsilon\sigma T^4 \tag{5}$$

In addition, a graybody has a constant emissivity less then unity and a selective radiator is one in which the emissivity varies with the wavelength [$\epsilon(\lambda)$].

When radiant energy is incident on a surface, it will be reflected, absorbed or transmitted as shown by the following equation:

$$\alpha+\rho+\tau=1 \tag{6}$$

where:

α = the fraction of energy absorbed,

ρ = the fraction of energy reflected,

τ = the fraction of energy transmitted.

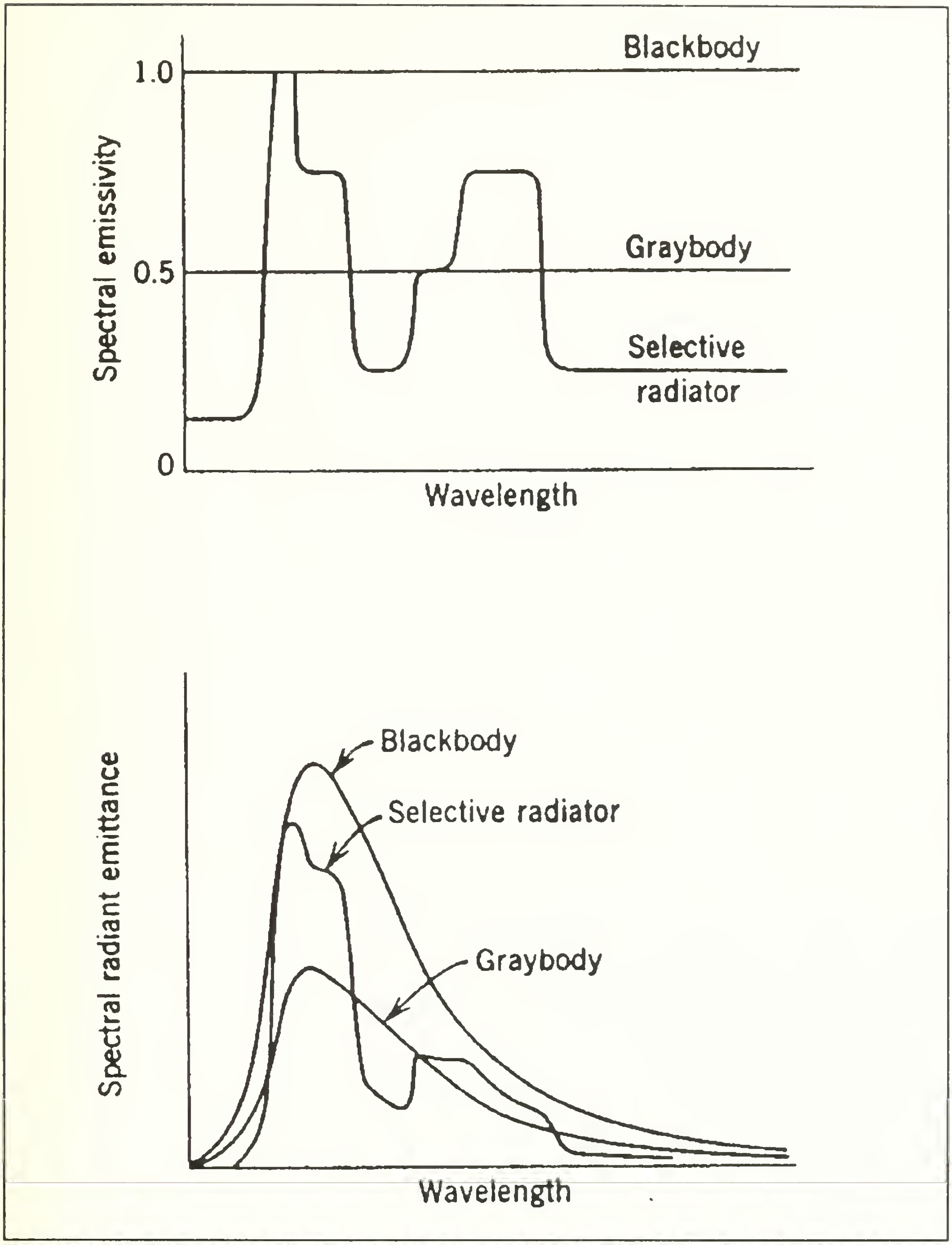

Figure 2.3 Spectral Emissivity and Spectral Radiant Emittance of Three Types of Radiator [Ref. 2]

By definition for an opaque object:

$$\epsilon = 1 - \rho \tag{7}$$

C. ATMOSPHERIC EFFECTS

As shown in the Figure 2.4 , the majority of energy radiated by an object at atmospheric temperatures (~ 300 °K) will be in the 3.0 - 14.0 μm region of the electromagnetic spectrum. The atmospheric transmittance is clearly a function of the wavelength which consequently produces windows in the 3.5 - 5.0 μm and 8.0 - 14.0 μm range. At other wavelengths the transmittance (τ) is diminished. The 8.0 - 14.0 μm range is generally used because it has the advantage of performing better in haze, which is typical for long slant paths through humid environments.

1. Lambert-Beer Law

The atmospheric transmittance [$\tau_a(\lambda)$] at a specific wavelength for a specific set of atmospheric conditions is delineated by the Lambert-Beer Law:

$$\tau_a(\lambda) = \exp(-\mu(\lambda) R) \tag{8}$$

where:

λ = the specific wavelength

μ = the extinction coefficient

R = the range or path length.

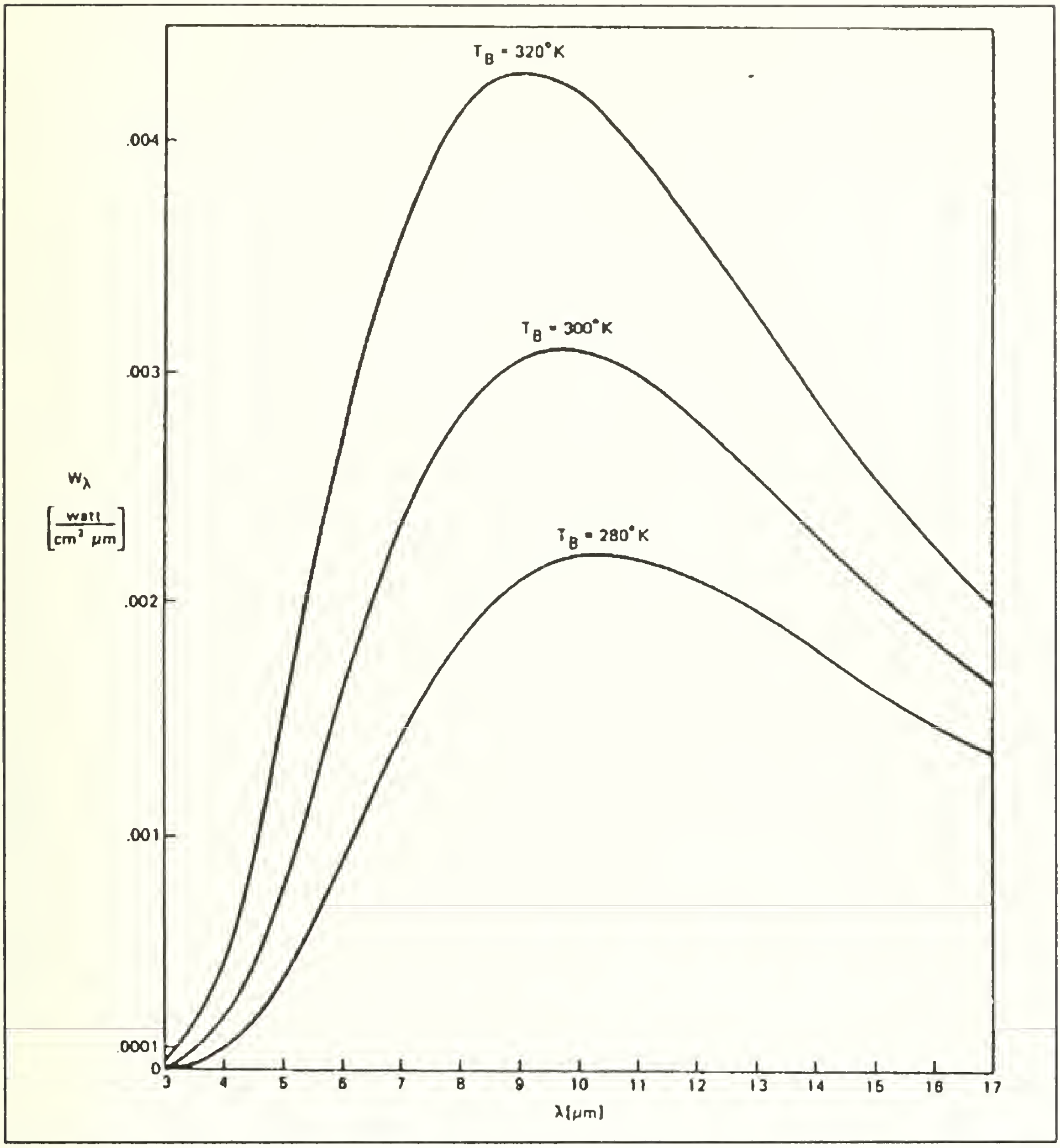

Figure 2.4 Spectral Radiant Emittance for Three Blackbody Temperatures [Ref. 4]

The average transmittance between two wavelengths is then written as:

$$\tau_a = \frac{1}{\lambda_2 - \lambda_1} \int_{\lambda_1}^{\lambda_2} \exp\left[-\mu(\lambda) R\right] d\lambda \tag{9}$$

2. Absorption and Scattering

Absorption and scattering are two means by which IR attenuates as it propagates through the atmosphere. The attenuation is generally referred to as atmospheric extinction. Extinction is also a function of the wavelength of the IR signal. Figure 2.5 shows the spectral transmittance measured over a 6000 foot horizontal path at sea level.

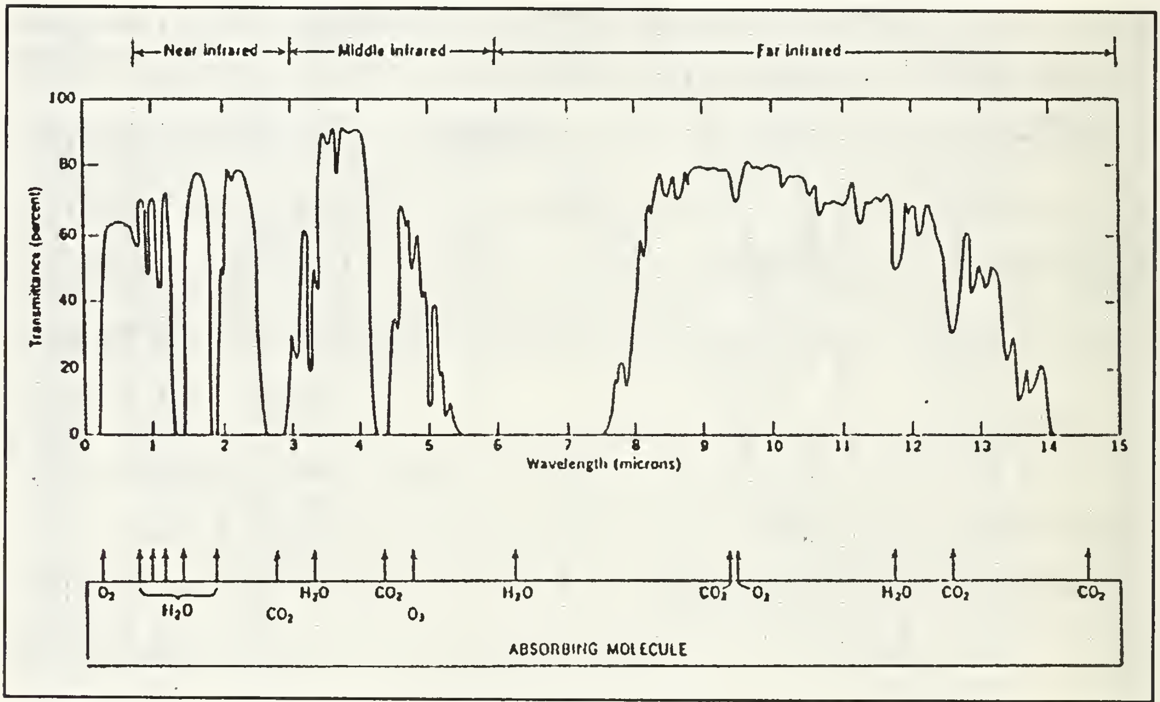

Figure 2.5 Infrared Windows [Ref. 2]

The total extinction coefficient is the sum of the coefficients for total absorption and total non-forward scattering as depicted in the following equation,

$$\mu=\mu_a+\mu_s \qquad (10)$$

where:

μ = Total extinction coefficient

μ_a = Extinction coefficient for total absorption

μ_s = Extinction coefficient for non-forward scattering

Absorption and scattering can then be further divided into the sum of molecular absorption, aerosol absorption, molecular scattering and aerosol scattering coefficients:

$$\mu_a = k_m + k_a \tag{11}$$

$$\mu_s = \sigma_m + \sigma_a \tag{12}$$

where:

k_m = Molecular absorption coefficient

k_a = Aerosol absorption coefficient

σ_m = Molecular scattering coefficient

σ_a = Aerosol scattering coefficient

Scattering by both aerosols and molecules has the greatest effect in the visible region, and absorption in the IR region of the electromagnetic spectrum.

Water, carbon dioxide, ozone, nitrous oxide, carbon monoxide, and methane are the principal causes of molecular absorption. [Ref. 4:p. 30] Absorption affects atmospheric transmission by attenuating thermal radiation which consequently limits the spectral range to the two windows described above.

There are four standard types of aerosols - maritime, continental, urban, and stratospheric. Maritime aerosols primarily consist of salt water particles. Wind speed dictates

the concentration of the salt particles which are released from the ocean. Organic material, iron, sulphates, and silicon are the main contributors to continental aerosols. Urban aerosols are composed mainly from pollution resulting from industrial products and are typically found around cities. Stratospheric aerosols are predominantly sulphates and volcanic ash or dust.

3. LOWTRAN 6

LOWTRAN is a Fortran program, developed by the Air Force Geophysics Laboratory (AFGL), that calculates atmospheric transmittance and thermal radiance. The frequency range for LOWTRAN is from 350 cm^{-1} to 40000 cm^{-1}. The LOWTRAN code calculates transmittance at low spectral resolution, primarily 20 cm^{-1} increments. The model contains code which calculates the refraction and earth curvature along the atmospheric slant paths. The atmosphere is handled as 33 layers from zero to a hundred kilometers.

The input to LOWTRAN consists of several "cards" or "input screens" which are used to define the atmospheric parameters for the model. If radiosonde data is used, the program will request data for the atmospheric layers. A maritime model is also included in the LOWTRAN code which includes the effects of wind and sea spray.

LOWTRAN 6 also provides the following four types of output [Ref. 5]:

1. path transmittance
2. path transmittance and path radiance
3. path transmittance and path radiance including single scattered contribution
4. directly transmitted solar irradiance

D. CONTRAST TRANSFER FUNCTION

How well a thermal imaging system is able to see a target against some background is highly dependent upon the radiation contrast. Radiation contrast is defined as:

$$C=\frac{(W_T-W_B)}{(W_T+W_B)} \tag{13}$$

where:

W_T = the target radiant emittance

W_B = the background radiant emittance

The contrast between target and background is frequently expressed as the temperature difference between them, ΔT, which will provide this contrast. For image analysis the criterion for target detection is that ΔT should exceed the minimum detectable temperature (MDT) for the sensor. The radiation contrast curves for four background temperatures are shown in Figure (2.5). [Ref. 4:p. 29]

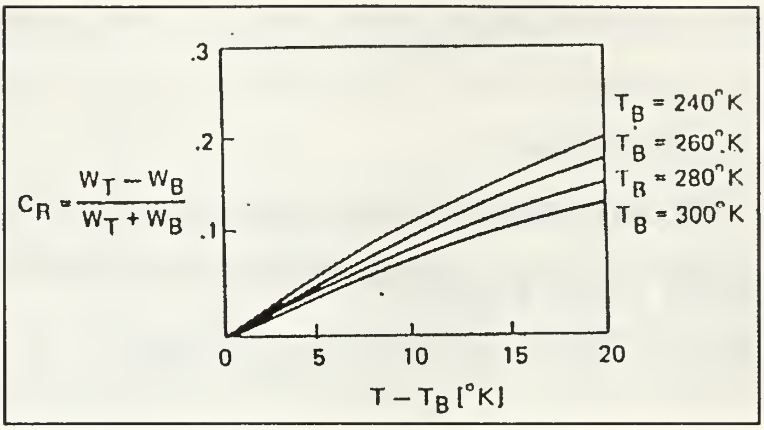

Figure 2.6 Radiation Contrast
(8 - 14 μm band)

III. DATA COLLECTION

A. GENERAL

The research vessel R/V POINT SUR was used in gathering data during the period 7 May - 11 May 1991 in conjunction with the biannual NPS student meteorology cruise. The R/V POINT SUR carries a full suite of automatically recording meteorological and oceanographic instruments. The ship also provided hourly observations of ship position, air temperature, sea temperature, weather conditions, visibility, sea state, ship speed and heading, and surface wind speed and direction. The ship launched Rawinsondes to record the air temperature, pressure, and relative humidity profiles in the atmosphere up to 10,000 feet. Fourteen thermistor temperature sensors were mounted on the ship at various locations to measure the skin temperature of the hull and stack. The sensors were used to validate the temperature measurements made by the AGA on 7 May 1991. During the cruise radiance contrast measurements and FLIR range observations were collected.

B. SHIP IMAGES RECORDING

An AGA Thermovision 780 (Figure 3.1) with an IBM AT personal computer running CATS 2.1 software was used to collect images in the 8-14 micrometer band of the R/V POINT

SUR at the Navy beach off NPS.[Ref. 6] CATS 2.1 is a software package which allows the acquisition and storage of thermal images on an IBM AT computer hard disk.[Ref. 7] The images were recorded of the ship from different angles at one-half mile and one mile as shown in Figure (3.2). The AGA had to be initialized with the ambient air temperature around the ship, the ship distance, the ship emissivity, and the atmospheric transmittance.

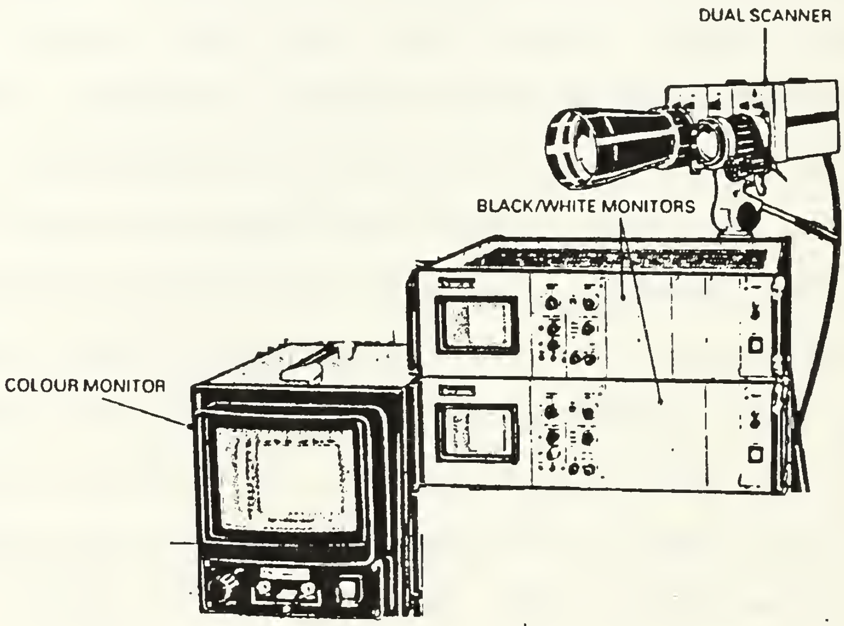

Figure 3.1 Dual Band AGA 780 Showing Scanner, Black and White Monitor and Color Monitor.

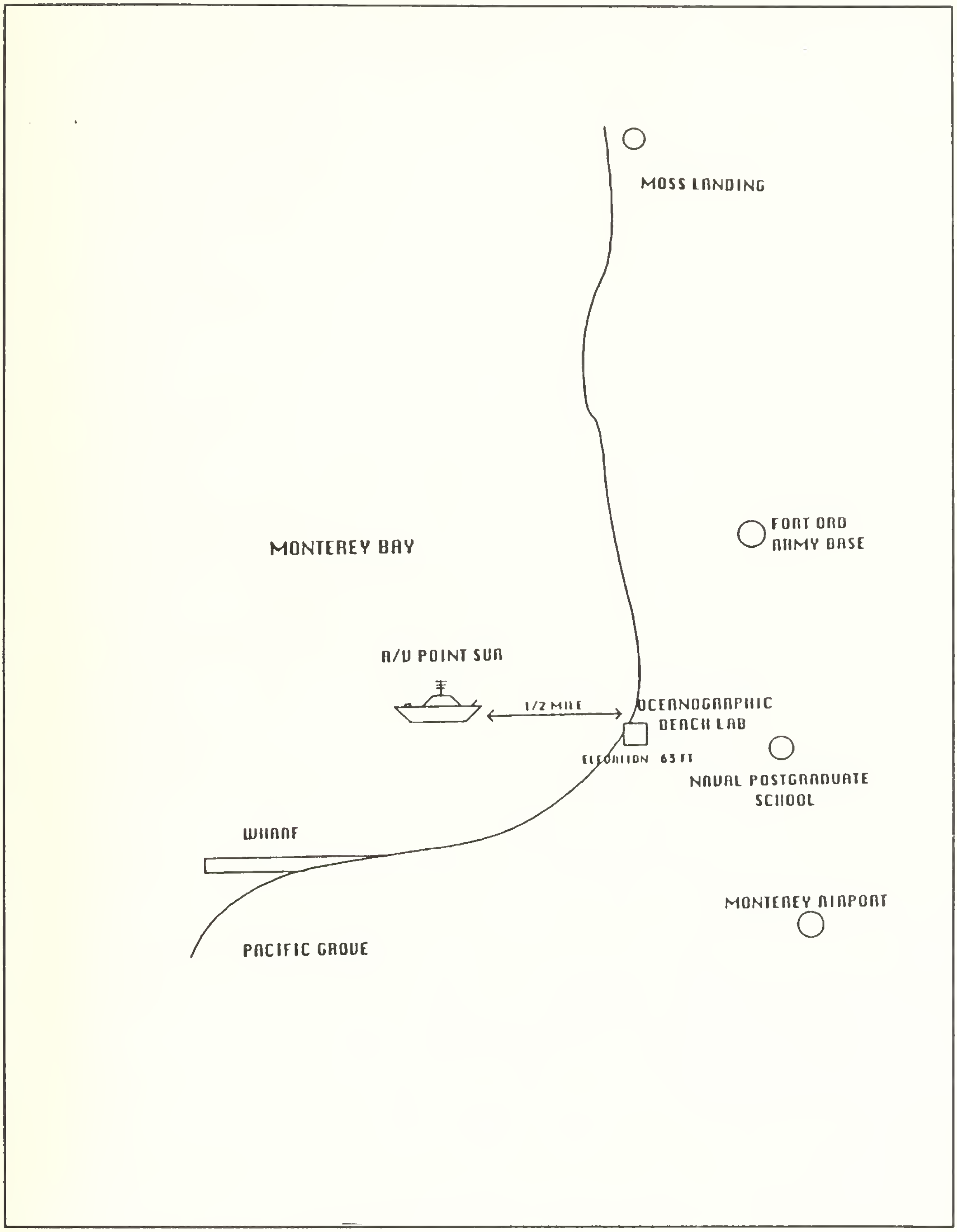

Figure 3.2 Site of Experiment

C. THERMISTOR DATA

The skin temperature measurements of the R/V POINT SUR were recorded using fourteen thermistors distributed over the ship as shown in Table 3.1 and depicted in Figure (3.3). A portable computer aboard the ship was used to collect the temperature values for the duration of the cruise.

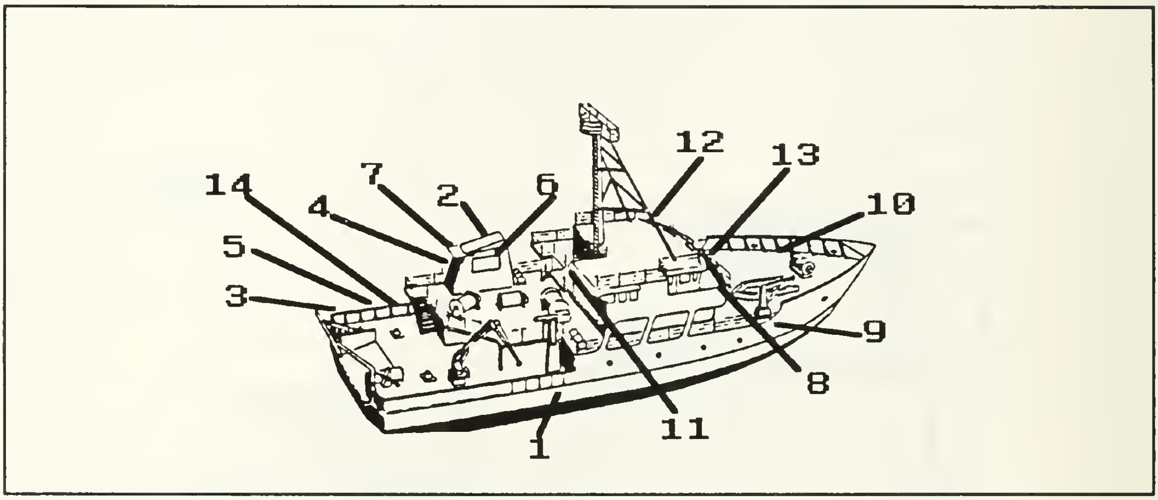

Figure 3.3 R/V Point Sur

TABLE 3.1 SENSOR LOCATIONS

R/V POINT SUR SENSOR LOCATION	SENSOR NUMBER
Starboard Aft	1
Port Top Stack	2
Aft Port	3
Aft Stack Rear	4

R/V POINT SUR SENSOR LOCATION	SENSOR NUMBER
Water Probe	5
Starboard Stack	6
Port Below Stack	7
Bow Boathouse	6
Bow Starboard	6
Port Bow	12
Aft Boathouse	11
Boathouse Port	12
Air Probe Bow	13
Deck Hoist	14

IV. DATA ANALYSIS

The sensor temperatures were evaluated and specific time segments were taken from the thermistor temperatures which corresponded with the time when the thermal images were taken. The temperatures from the thermistors were then used as a comparison to the temperatures measured by the AGA camera. A listing of the image files with a brief description of what the thermal images consist of is included in Appendix B. A radiosonde was launched approximately 12:30 p.m. local time which was approximately an hour to an hour and a half after the measurements were taken. The recorded radiosonde data (Appendix A) was then input into LOWTRAN 6 to determine the atmospheric transmittance (τ_a).

The AGA images were processed to evaluate the temperature distributions of the ship. The biggest disparity between the actual (i.e. thermistor) and image temperatures was around the ship stack; this was a result of the temperatures being out of the range of the thermal settings.

A. AGA SYSTEM THERMAL MEASUREMENTS

1. Thermal Measurement Techniques

The AGA utilizing the CATS program reads out the distribution of source temperatures based on stored calibration constants and a software correction for radiance

reflected from the target, path losses, and path radiance, dependent on range and atmospheric transmittance. The correction for transmission loss requires use of the path transmittance τ_a. This may be provided by LOWTRAN computations based on known meteorological parameters, or if this is not available using the empirical short path approximation of Equation 14 using the standard atmosphere value of extinction coefficient α. [Ref. 8]

$$\tau_a = \exp[-\alpha(\sqrt{d}-1)] \qquad \textbf{(14)}$$

where:

α = the atmospheric attenuation constant

d = the distance to the object

The above equation is good only for short distances. The transmittance computed by LOWTRAN is more accurate and was used in this study for atmospheric correction of the AGA system output. The AGA uses the following equation in determining the thermal measurement [Ref. 7]:

$$P_i = \tau_a \varepsilon_o P_o + \tau_a (1-\varepsilon_o) P_s + (1-\tau_a) P_a \quad [Watt] \qquad \textbf{(15)}$$

where:

P_i = total radiant power received by the system

τ_a = the atmospheric transmittance

ϵ_o = the object's emissivity

P_o = radiant power from the object as a blackbody

P_s = the radiant power from the object's surroundings

P_a = the radiant power received from the atmosphere along the path as a blackbody

Since the "thermal value", a quantity proportional to the detector output, of the system is also proportional to the received radiant power, the above equation can be rewritten as:

$$I_i=\tau_a\varepsilon_o I_o+\tau_a(1-\varepsilon_o)I_s+(1-\tau_a)I_a \quad [ThermalUnits] \qquad \textbf{(16)}$$

where:

I = the thermal value of the corresponding radiation sources.

The received thermal value (Equation 17), was then substituted into Equation 16.

$$I_i=L+i \qquad \textbf{(17)}$$

where:

L = the thermal level setting on the monitor chassis

i = a fractional portion of the thermal range

With the above substitution the object's thermal value could then be isolated as:

$$I_o=(L+i)/\tau_a\varepsilon_o-(1/\varepsilon_o-1)I_s-1/\varepsilon_o(1/\tau_a-1)I_a \qquad \textbf{(18)}$$

Equation 18 expresses the equivalent emission thermal value of the target in terms of the total measured thermal value (L + i), the equivalent thermal value of the ambient flux reflected

from the target (I_s), and the equivalent path radiance thermal value (I_a).

The "thermal values" I are expressed in terms of equivalent source black body temperature through direct calibration using "black body" sources at known temperature (and emissivity) and are found to match the empirical relationship of Equation 19, where the calibration constants are determined by curve fitting. The equivalent source radiance is obtained from the radiation laws.

$$I=A/[C\exp(B/T)-1) \qquad \textbf{(19)}$$

where:

A, B, C = predetermined calibration constants

The temperatures measured by the AGA are expressed in isotherm units which is an arbitrary unit of measurement proportional to received power.

2. Thermal Measurement Data

The following four figures (Figures 4.1 - 4.4) are black and white representations of color scale computer displayed images of the R/V POINT SUR, starboard and port sides, at one half mile and one mile. Tables 4.1 - 4.4 following each figure give the variables used by the AGA system to compute the thermal images. These figures are generated using the AGACAT program developed at NPS [Ref. 9]. This program includes the capability of displaying a) the temperature profile along a vertical or

horizontal line through a selected pixel number, b) the spot temperature of a pixel defined by the pixel number coordinates (e.g. 91, 74) selected by cursor, c) the average temperature (TA) of the pixels included in a rectangular box selected using a "mouse", and d) the temperature difference (DT) between the interior of the box and the surrounding region limited by an additional box. The different shades represent the temperature range distributions corresponding to the scale on the left of the image. In the image the isotherm levels are arranged such that each shade represents an equal number of isotherm units. The isotherm units are then converted to a temperature using stored calibration constants. Additional information included on the screen image includes image number, field of view, aperture, wavelength, waveband, and filters.

Using these images the radiance temperature distributions were compared to the actual temperatures recorded by the temperature sensors located on the ship. There is error due to the pixel size of the image which corresponds to approximately 1 square meter on the ship, whereas the sensor is approximately 1 square centimeter. This error is also dependent upon the range of the ship. A ship much further away would result in the pixel size of the image covering a larger area of the ship. The ship's range from the AGA 780's location is computed using the following geometrical relationship:

$$R=(S_o/\tan\theta)(S_i/w)^{-1}=(wS_o/\tan\theta)(1/S_i) \quad [m] \tag{20}$$

where:

R = ship's range

S_o = ship's length (41.2m)

S_i = image length in cm

w = display screen width (13cm)

θ = system field of view (7 degrees)

The variables used in computing the images were corrected to reflect the transmittance that LOWTRAN 6 predicted at 825 meters (one half mile) and 1650 meters (one mile). The variable for the emissivity of the ship was also corrected to .97 from 1.0. For the images produced at 1650 meters the thermal level was set at 4 so that the range of temperatures agreed with the sensors.

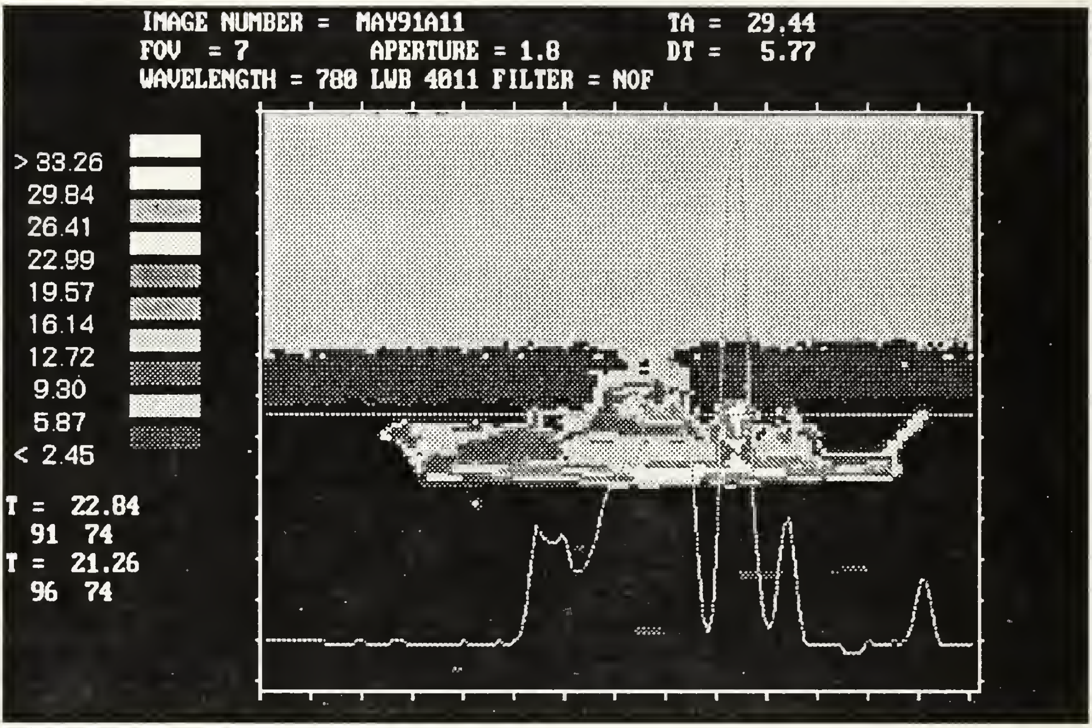

Figure 4.1 Portside of R/V POINT SUR at 825 Meters. Temperature Profile Shown for Pixel Row 74.

TABLE 4.1 AGA SYSTEM VARIABLES

Variable	Value
Object Distance	825 m
Transmittance	.7757
Atmospheric Temperature	294.7 K
Ambient Temperature	291.3 K
Emissivity	.97

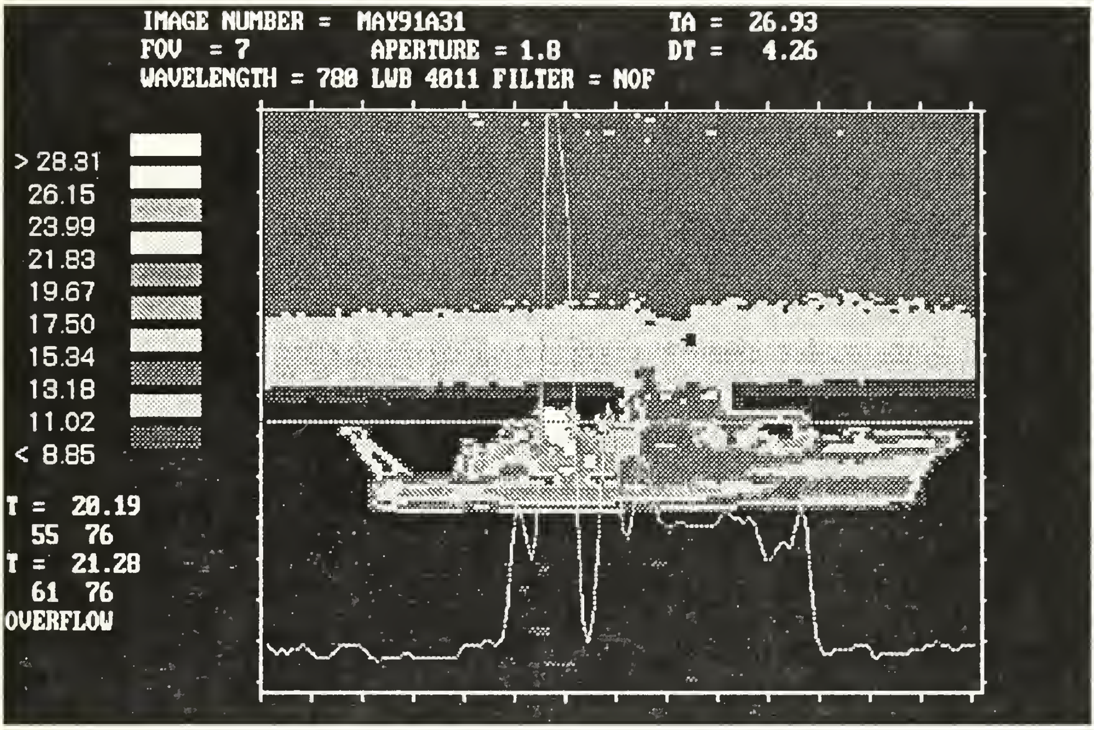

Figure 4.2 Starboard Side of R/V POINT SUR at 825 Meters. Temperature Profile Shown for Pixel Row 76.

TABLE 4.2 AGA SYSTEM VARIABLES

Variable	Value
Object Distance	825 m
Transmittance	.7757
Atmospheric Temperature	294.7 K
Ambient Temperature	291.3 K
Emissivity	.97

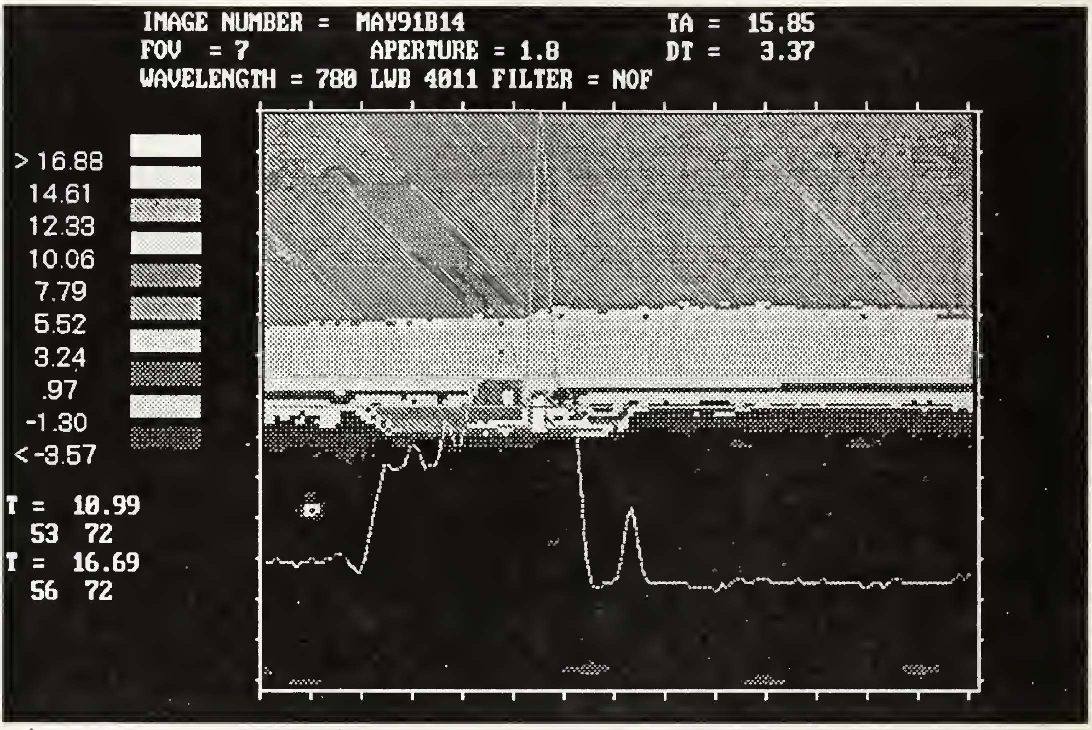

Figure 4.3 Portside of R/V POINT SUR at 1650 Meters. Temperature Profile Shown for Pixel Row 72.

TABLE 4.3 AGA SYSTEM VARIABLES

Variable	Value
Object Distance	1650 m
Transmittance	.6230
Atmospheric Temperature	294.7 K
Ambient Temperature	291.3 K
Emissivity	.97

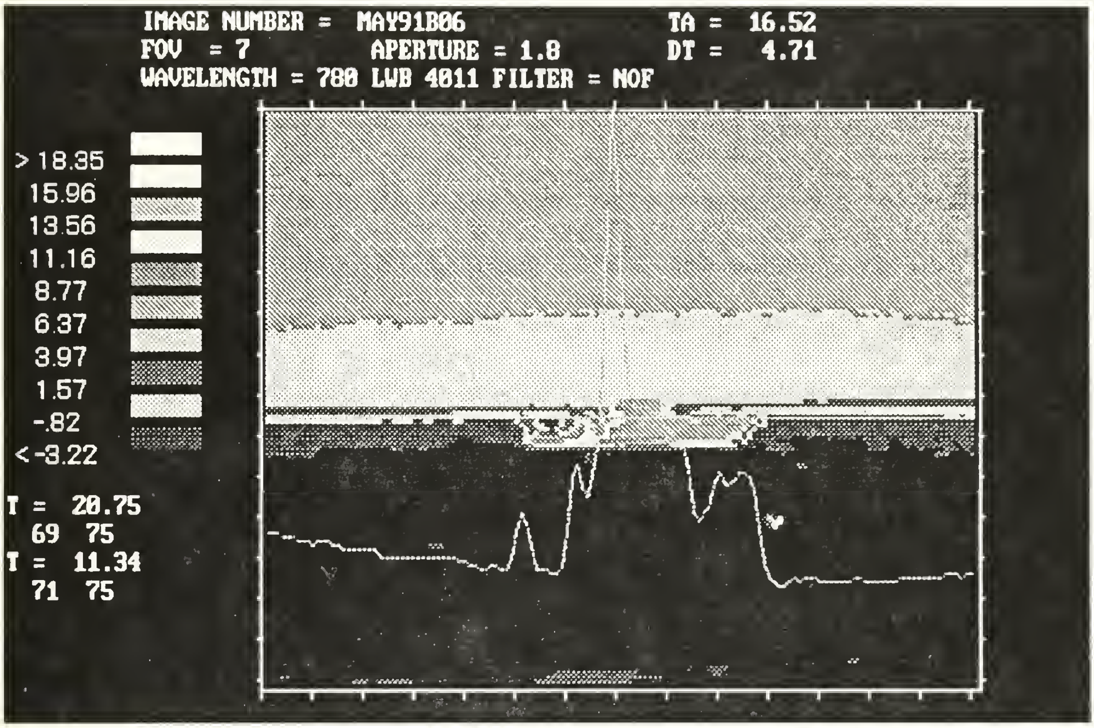

Figure 4.4 Starboard Side of R/V POINT SUR at 1650 Meters. Temperature Profile Shown for Pixel Row 75.

TABLE 4.4 AGA SYSTEM VARIABLES

Variable	Value
Object Distance	1650 m
Transmittance	.6230
Atmospheric Temperature	294.7 K
Ambient Temperature	291.3 K
Emissivity	.97

Once all variables were changed in the images a comparison was made of the actual temperatures produced by the sensors to the temperatures derived by the AGA system. These comparisons are shown in Figures 4.5 and 4.6. The comparisons were produced for ranges of 825 and 1650 meters.

Figure 4.5 shows that the temperatures were very close at 825 meters. The mean for the temperature difference between the ship and AGA system was .132 with a standard deviation of .096 degrees celsius.

In Figure 4.6 there was a larger error in the temperature distributions at 1650 meters. At this range the mean temperature difference was .973 with a standard deviation of .453 degrees celsius. Pixel size was probably a factor in the temperature difference. At twice the distance, the pixel size corresponds to a larger area of the ship. The dominant temperature in the ship area corresponding to the pixel could obscure the variations in temperature. For this reason temperatures could not be found for sensors eight and eleven.

In most cases the temperatures were underestimated by the AGA system. The differences in temperatures were so small that they should be considered insignificant and could have been the result of several different factors such as ship range, transmittance, etc. This comparison between the thermistor sensors and the radiometric measurements gives confidence in prediction of the radiant signature of the target under "at-sea" conditions.

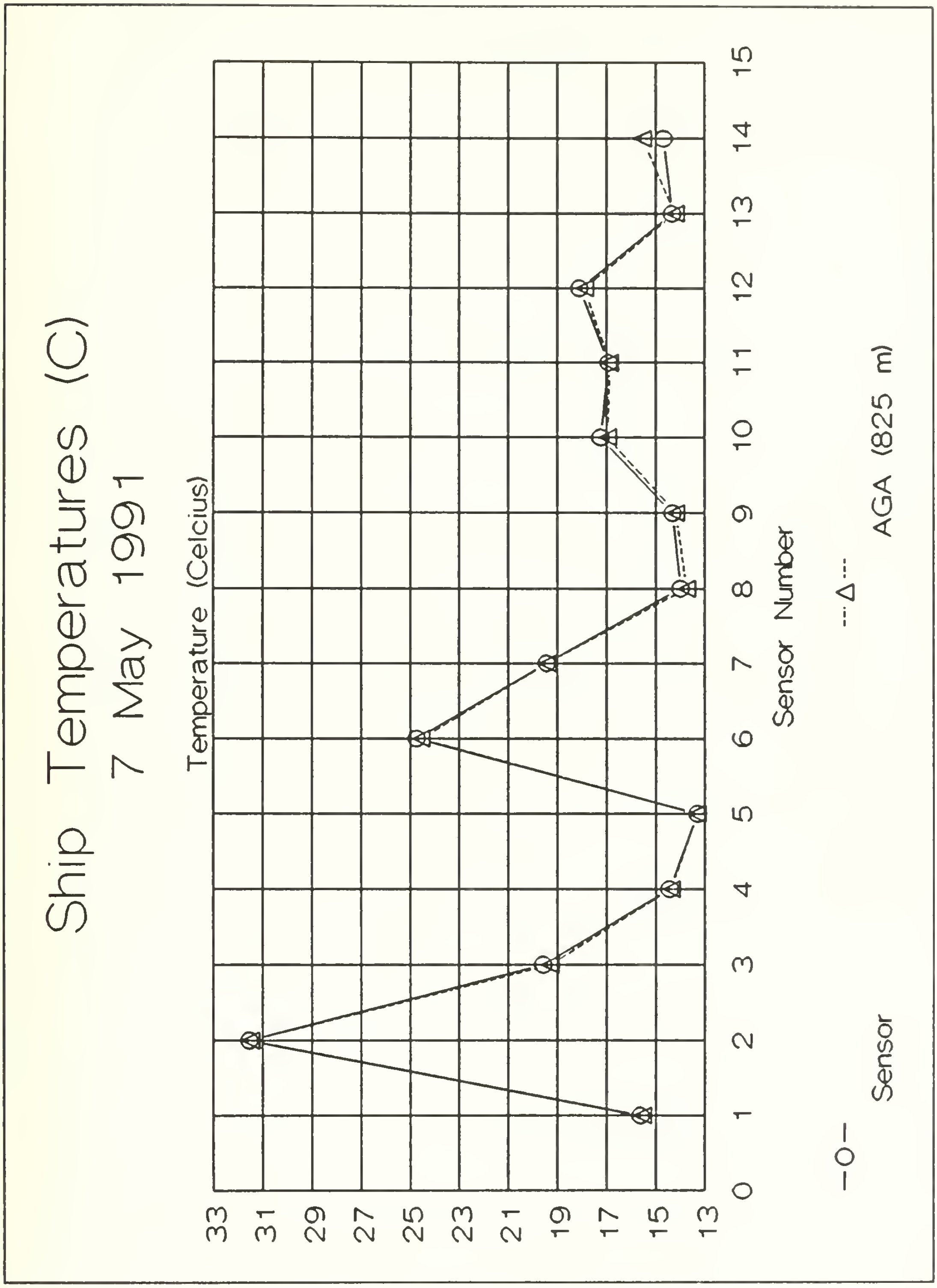

Figure 4.5 Ship Temperatures at 825 meters

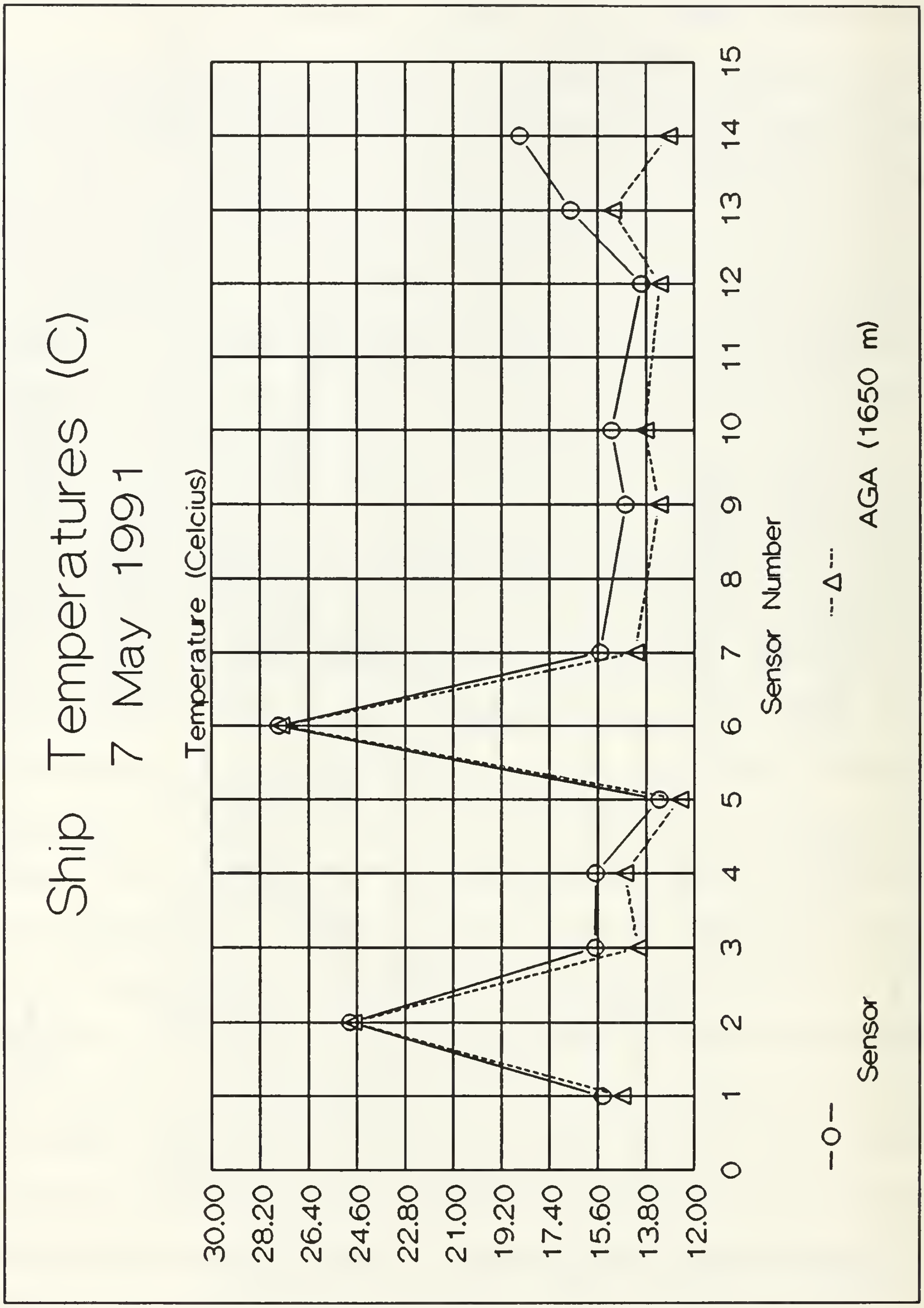

Figure 4.6 Ship Temperatures at 1650 meters

B. PATH RADIANCE VALIDATION

As discussed in Chapter II, how well a thermal imaging system is able to see a target against a background is highly dependent upon the radiation contrast. It can be shown mathematically, that adding the path radiance (W_p) to:

$$C=\frac{W_T-W_B}{W_T+W_B} \tag{21}$$

results in:

$$C=\frac{(W_T+W_P)-(W_B+W_P)}{(W_T+W_P)+(W_B+W_p)} \tag{22}$$

which then can be reduced to:

$$C=\frac{W_T-W_B}{2W_P+W_T+W_B} \tag{23}$$

Therefore, the above equation states that as the path radiance increases the contrast decreases: this was evident when the images were made of the R/V POINT SUR.

The path radiance for different viewing angles was computed using LOWTRAN 6 and a computer program (AGARADIA) by Professor Milne to compute radiances of the image files produced by the AGA system. Figure 4.7 shows an image of the R/V POINT SUR at a range of 825 meters with values associated with IA, I1, I2, and I3. The values corresponding to the variables IA, I1, I2, and I3 are the radiated, detected,

reflected, and path thermal values of the image (target radiance) as shown in following equations:

$$I_D = I_T \epsilon_T \tau_a + I_R (1-\epsilon_T) \tau_a + I_P (1-\tau_a) \quad \textbf{(24)}$$

$$I1 = IA + I2 + I3$$

where:

I_T = target radiated thermal value

I_D = detected thermal value

ϵ_T = emissivity of the target

τ_a = atmospheric transmittance

I_R = target reflected thermal value

I_P = path radiated thermal value

The AGA path radiated thermal value computed by the computer program was then compared to the path radiance calculated using LOWTRAN 6.

LOWTRAN 6 calculates the path radiance by doing a numerical integration over wavelength, and for each atmospheric layer, of the sum of the atmospheric absorption times the scattering times the blackbody radiation from the atmospheric layer, and the blackbody radiation from the boundary times the average total transmittance. The model can also compute the scattering of radiation into the atmospheric path. [Ref. 5]

The values associated with IA, I1, I2, and I3 are computed as thermal values of the total received power of the image, therefore, the values in the following graphs are represented

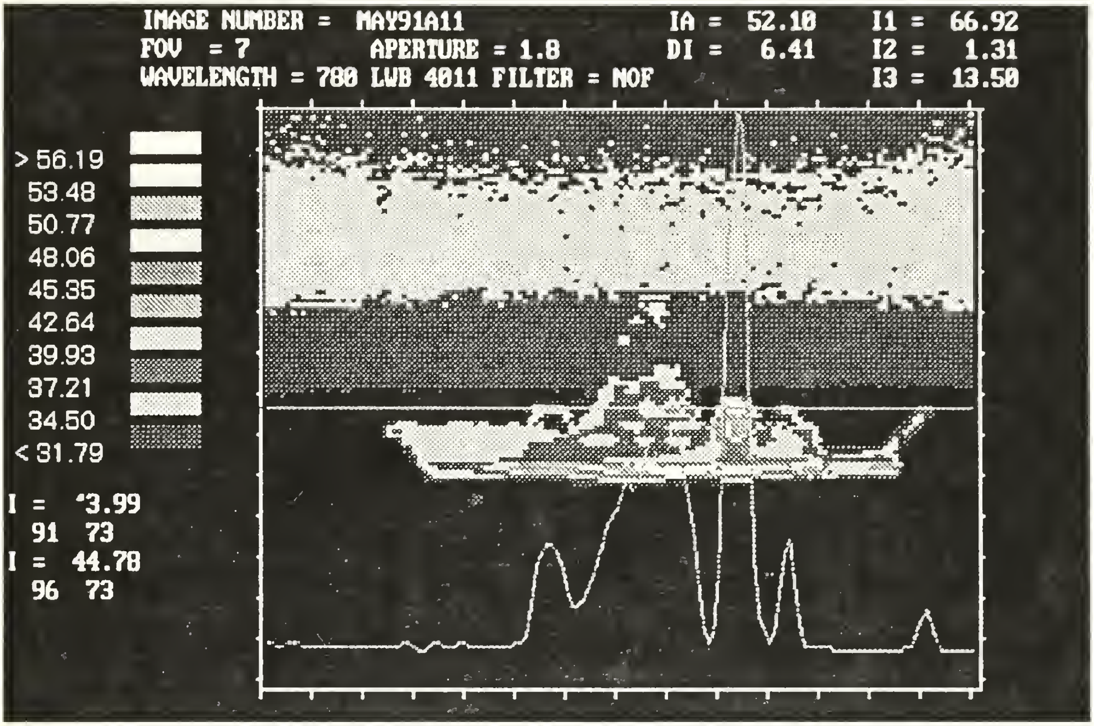

Figure 4.7 R/V Point Sur at 825 meters

as percentages of the total radiance so that comparisons can be made with the LOWTRAN 6 calculations. Figure 4.8 shows the contribution that path, reflected, and radiated radiances measured by the AGA system make toward the total radiance of the target as a function of zenith angle. The zenith angle of 90.585, shown in Figure 4.8, corresponds with 2000 meters and 91.699 degrees corresponds with 825 meters. Varying zenith angle varies the slant path for both the target and background. Therefore, radiated power received from the target will decrease as the zenith angle decreases, and reflected power received from the target will decrease as the zenith angle decreases, and power received from path radiance will increase as the zenith angle decreases. As the zenith angle

approaches ninety degrees, the path radiance is the major contributor to the total received radiant power. The rapid drop in the path radiant power with the increasing zenith angle is due to the shorter slant paths to the earth. The AGA system measured minuscule changes in the target reflected radiant power which shows in Figure 4.8 as a straight line. The target radiant received power increases as the zenith angle increases from ninety degrees, due to the decrease in path length. The graph in Figure 4.9, using data produced with AGACATS software and LOWTRAN 6, is consistent with similar research conducted by Naval Ocean Systems Center (NOSC), San Diego. [Ref. 10]

The AGA measured path radiance was then compared to the fractional path radiance component of received power computed by LOWTRAN 6 (Figure 4.9) using the Navy Maritime Aerosol Model and an air mass factor of three. The AGA measurements varied over the range from twenty-five to seventy-five percent, while the LOWTRAN fraction ranges only from seventy-five to eight-five percent, with the biggest discrepancy occurring at the short paths. This discrepancy suggests a defficiency in calculations with either the AGA path radiance algorithm or the LOWTRAN 6 calculations. Questions have been raised previously with respect to the accuracy of LOWTRAN in the region close to the horizon: however here the discrepancy is greatest at the shorter path lengths. LOWTRAN calculated the zenith angle for the infrared horizon to be at 90.18

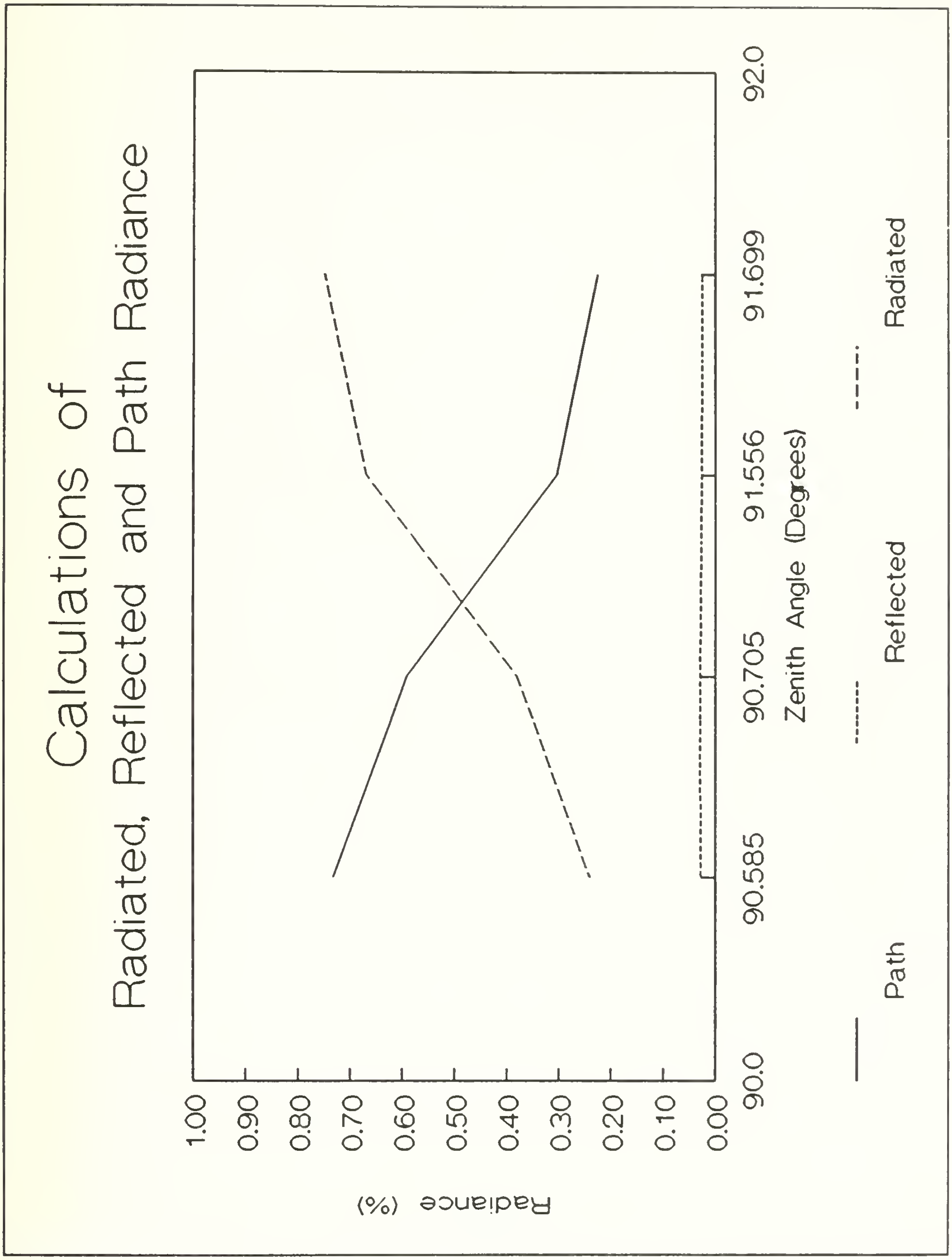

Figure 4.8 Calculated Path, Reflected, and Radiated Radiances Percentages

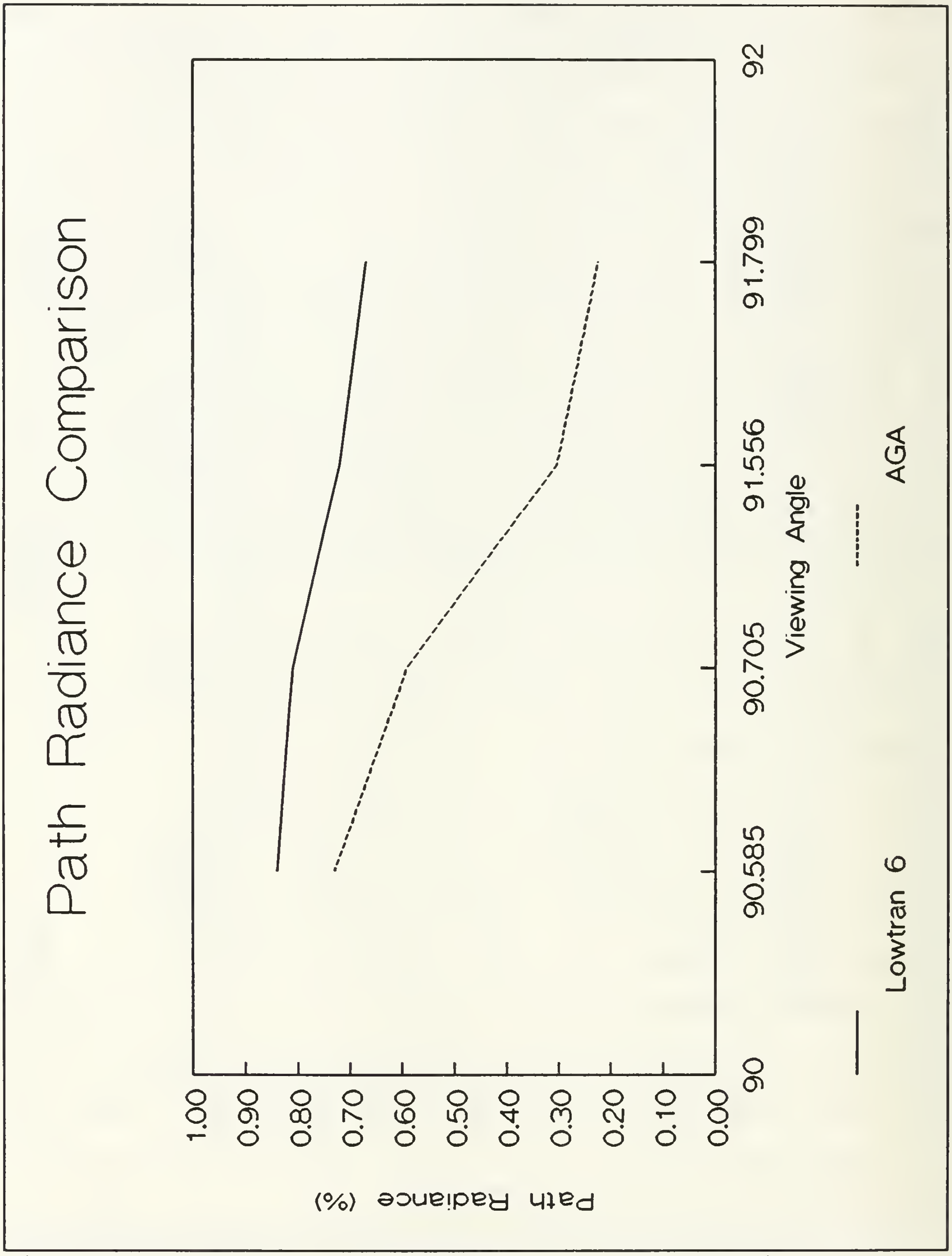

Figure 4.9 Calculated Lowtran 6 and AGA Path Radiance Percentages.

degrees which was the point at which the refracted ray path first hit the earth. A large difference in these percentages appears as the zenith angle increases. The measured radiances fall off sharply with increasing zenith angles. A contributing factor for the differences may be due to the radiosonde input to LOWTRAN 6. The radiosonde balloon was launched approximately one and a half hours after the AGA measurements were taken. If the radiosonde data was outside the 'window', it could be an additional reason for the difference between the measured and calculate radiances.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Thermal images of the R/V Point Sur were taken on 7 May 1991 off the Naval Postgraduate School Beach. The image file variables were then updated to reflect the actual transmittance computed from LOWTRAN 6. The range and emissivity variables were also updated to reflect the actual distances and true emissivity of the ship. The changes in the variables allowed the AGA measured temperatures to agree with the actual ship temperatures to within one degree celsius.

The temperatures of the ship were then compared between the AGA system and the fourteen thermistors which were attached to the ship. The mean and standard deviation of the ship temperature differences were then computed.

The path radiance was then computed using LOWTRAN 6 for different ranges. The path radiances from the thermal images were also measured utilizing the AGACATS software. The measured radiances were then compared to the LOWTRAN 6 predicted path radiances.

B. CONCLUSIONS

In comparing the temperature distributions produced by the sensors and the AGA system with corrections, it was shown that

the AGA system slightly underestimated the temperatures. It was concluded the temperature differences were insignificant since they were less than one degree celsius. Some of the images had an overflow for the temperatures, but that was due to the thermal range settings which did not allow some of the higher temperatures to be measured.

The influence of path radiant power as measured by the AGA system was consistent with similar studies completed at NOSC. The power received from path radiance became more dominant as the slant path ranges increased due to absorption by the atmosphere. The AGA measurements of power received from path radiance varied over the range from twenty-five to seventy-five percent while the LOWTRAN fraction of path radiance ranged from seventy-five to eighty-five percent. The largest difference between the calculations occurred at the shorter path lengths. This disparity suggests that either the AGA or LOWTRAN algorithms has an erroneous algorithm. The differences in the calculated path radiances and measured radiances could also have been caused by the accuracy of the inputs. A contributing factor may have been the delay of an hour to an hour and a half between the image data and the radiosonde data input to LOWTRAN 6.

C. RECOMMENDATIONS

Since the path radiance provides a significant contribution to the total radiance observed from a target at

long slant paths an effort should be made to incorporate or model the path radiance into UFLIR. UFLIR is based on the LOWTRAN 3 model which did not take into account path radiance.

There is a limited database with which to work with since in almost all of the experiments problems occurred in the data collection, for example, radiosonde balloons being released later then required due to equipment malfunction. Therefore, continued work in collecting measurement data should done to provide more precise data for analysis. More measurements should also be made under a variety of weather conditions.

APPENDIX A RADIOSONDE DATA

RADIOSONDE LAUNCHES STUDENT CRUISE MAY 1991

#	FILE	DATE	TIME	TIME	EVENT
0	PS060523	05-06-91	21:03 GMT	14:03 local	test
1	PS070519	05-07-91	19:38 GMT	12:30 local	18z/FLIR (late)
2	PS070524	05-07-91	23:51 GMT	16:51 local	24z
3	PS080506	05-08-91	05:35 GMT	22:30 local	6z
4	PS080513	05-08-91	13.33 GMT	06:33 local	12z (late)
5	PS080518	05-08-91	17:37 GMT	10:37 local	18z
6	PS080521	05-08-91	21:26 GMT	14:30 local	U2
7	PS090500	05-09-91	23:33 GMT	16:33 local	24z
8	PS090506	05-09-91	05:40 GMT	22:40 local	6z
9	PS090512	05-09-91	11:36 GMT	04:36 local	12z
10	PS090518	05-09-91	17:39 GMT	10:39 local	18z
11	PS090521	05-09-91	21:22 GMT	14:22 local	U2 / FLIR P3
12	PS100500	05-10-91	23:35 GMT	16:35 local	24z
13	PS100506	05-10-91	05:36 GMT	22:36 local	6z
14	PS100512	05-10-91	11:37 GMT	04:37 local	12z

Radiosonde PS070519

I	Z (KM)	P (MB)	T (K)
1	.02	1017.900	285.4
2	.22	993.900	284.4
3	.42	970.100	288.4
4	.62	947.900	290.9
5	.76	932.500	290.5
6	.94	912.700	289.1
7	1.10	896.400	288.4
8	1.29	876.000	287.8
9	1.47	857.800	288.4
10	1.61	843.300	287.9
11	1.76	828.400	287.1
12	1.91	813.600	286.4
13	2.07	798.200	284.9
14	2.33	774.200	283.3
15	2.47	760.900	282.1
16	2.62	747.100	281.5
17	2.74	736.600	280.6
18	2.87	725.500	279.6
19	2.99	714.800	278.6
20	3.14	701.300	278.4
21	3.22	694.500	277.9
22	3.37	681.900	277.0
23	3.56	666.400	276.1
24	3.81	646.300	275.3
25	4.01	630.400	274.4
26	4.17	617.600	273.5
27	4.33	605.600	272.3
28	4.55	589.300	271.1
29	4.74	574.800	270.8
30	4.97	558.200	269.5
31	5.13	547.700	268.4
32	5.32	534.100	267.0
33	5.67	510.700	264.5

APPENDIX B AGA DATA TAKEN MAY 7 1991

FILE NAME	SUBJECT	COMMENTS
MAY91A01.IMG	BLACK BODY	CALIBRATION OF SYSTEM IN LABORATORY
MAY91A02.IMG	BLACK BODY	CALIBRATION OF SYSTEM IN LABORATORY
MAY91A03.IMG	BLACK BODY	CALIBRATION OF SYSTEM IN LABORATORY
MAY91A04.IMG	BLACK BODY	CALIBRATION OF SYSTEM IN LABORATORY
MAY91A05.IMG	BARGE	TARGET FOR TESTING AND FOCUSING
MAY91A06.IMG	BARGE	AGA CAMERA AND EQUIPMENT
MAY91A07.IMG	POINT SUR	APPROACHING THE HORIZON
MAY91A08.IMG	POINT SUR	STILL APPROACHING
MAY91A09.IMG	POINT SUR	APPROX ONE MILE AWAY
MAY91A10.IMG	POINT SUR	PORT SIDE ONE HALF MILE AWAY
MAY91A11.IMG	POINT SUR	PORT SIDE SHIP'S HEADING 270 DEGREES
MAY91A12.IMG	POINT SUR	PORT SIDE (UNDERFLOW)
MAY91A13.IMG	POINT SUR	PORT SIDE
MAY91A14.IMG	POINT SUR	PORT SIDE
MAY91A15.IMG	POINT SUR	PORT SIDE
MAY91A16.IMG	POINT SUR	PORT SIDE
MAY91A17.IMG	POINT SUR	PORT SIDE
MAY91A18.IMG	POINT SUR	PORT STERN SHIP'S HEADING 315 DEGREES
MAY91A19.IMG	POINT SUR	PORT STERN SHIP'S HEADING 325 DEGREES
MAY91A20.IMG	POINT SUR	PORT STERN SHIP'S HEADING 315 DEGREES
MAY91A21.IMG	POINT SUR	PORT STERN
MAY91A22.IMG	POINT SUR	PORT STERN - WITH FISHING BOAT
	FISHING BOAT	STARBOARD SIDE WITH WAKE FOLLOWING
MAY91A23.IMG	POINT SUR	STERN - WITH ANOTHER FISHING BOAT
	FISHING BOAT	PORT SIDE WITH WAKE FOLLOWING
MAY91A24.IMG	POINT SUR	STERN
MAY91A25.IMG	POINT SUR	STERN
MAY91A26.IMG	POINT SUR	STARBOARD STERN
MAY91A27.IMG	POINT SUR	STARBOARD
MAY91A28.IMG	POINT SUR	STARBOARD
MAY91A29.IMG	POINT SUR	STARBOARD
MAY91A30.IMG	POINT SUR	STARBOARD STERN
MAY91A31.IMG	POINT SUR	STARBOARD
MAY91A32.IMG	POINT SUR	STARBOARD
MAY91A33.IMG	POINT SUR	STARBOARD
MAY91A34.IMG	POINT SUR	STARBOARD
MAY91A35.IMG	POINT SUR	PORT BOW WITH WAKE
MAY91A36.IMG	POINT SUR	STARBOARD
MAY91A37.IMG	POINT SUR	STARBOARD
MAY91A38.IMG	POINT SUR	STARBOARD
MAY91A39.IMG	POINT SUR	STARBOARD
MAY91A40.IMG	POINT SUR	STARBOARD AND BOUY
MAY91A41.IMG	POINT SUR	STARBOARD
MAY91A42.IMG	POINT SUR	STARBOARD AND SMALL BOAT

MAY91A43.IMG	POINT SUR	STARBOARD PLUS WAKE
MAY91A44.IMG	POINT SUR	STARBOARD PLUS WAKE
MAY91A45.IMG	POINT SUR	PORT PLUS WAKE
MAY91A46.IMG	POINT SUR	PORT PLUS WAKE
MAY91A47.IMG	POINT SUR	PORT PLUS WAKE
MAY91A48.IMG	POINT SUR	PORT PLUS WAKE
MAY91A49.IMG	POINT SUR	PORT PLUS WAKE
MAY91A50.IMG	POINT SUR	PORT PLUS WAKE

MAY91B01.IMG	POINT SUR	PORT WITH WAKE
MAY91B02.IMG	POINT SUR	PORT WITH WAKE AND BOUY
MAY91B03.IMG	POINT SUR	PORT WITH WAKE AND BOUY
MAY91B04.IMG	POINT SUR	STERN
MAY91B05.IMG	POINT SUR	STARBOARD WITH BOUY
MAY91B06.IMG	POINT SUR	STARBOARD WITH BOUY
MAY91B07.IMG	POINT SUR	STARBOARD WITH BOUY
MAY91B08.IMG	POINT SUR	STARBOARD WITH BOUY
MAY91B09.IMG	POINT SUR	STARBOARD WITH BOUY
MAY91B10.IMG	POINT SUR	STERN WITH BOUY
MAY91B11.IMG	POINT SUR	PORT WITH BOUY
MAY91B12.IMG	POINT SUR	PORT WITH BOUY
MAY91B13.IMG	POINT SUR	PORT WITH BOUY
MAY91B14.IMG	POINT SUR	PORT WITH BOUY
MAY91B15.IMG	POINT SUR	PORT WITH BOUY
MAY91B16.IMG	POINT SUR	PORT WITH BOUY
MAY91B17.IMG	POINT SUR	PORT WITH BOUY
MAY91B18.IMG	POINT SUR	PORT WITH BOUY
MAY91B19.IMG	POINT SUR	PORT WITH BOUY
MAY91B20.IMG	POINT SUR	PORT WITH SMALL BOAT IN FRONT
MAY91B21.IMG	POINT SUR	PORT WITH SMALL BOAT IN FRONT
MAY91B22.IMG	POINT SUR	PORT
MAY91B23.IMG	POINT SUR	PORT WITH SMALL BOAT IN FRONT
MAY91B24.IMG	POINT SUR	PORT WITH SMALL BOAT IN FRONT

APPENDIX C THERMISTOR TEMPERATURES

Hull Temperatures of R/V Point Sur

10:30 a.m. - 12:00 noon 7 May 1991

The time in the following data is computed as the number of seconds from the beginning of the month local time.

<u>Time</u> <u>Sensor Number</u> * - denotes calibration sensor

	*	1	2	3	4	5	6	7	*	8	9	10	11	12	13	14
556474	25.001	14.204	31.041	19.611	14.161	12.951	23.851	19.404	25.001	13.591	12.663	17.414	16.462	17.962	15.437	14.317
556494	25.001	14.214	31.175	19.651	14.165	12.981	23.965	19.435	25.001	13.590	12.666	17.409	16.520	17.971	15.335	14.325
556514	25.001	14.221	31.133	19.642	14.169	12.994	24.223	19.477	25.001	13.599	12.673	17.388	16.537	17.982	15.295	14.341
556534	25.001	14.228	31.153	19.683	14.203	12.997	24.256	19.507	25.001	13.599	12.679	17.377	16.555	17.993	15.394	14.357
556554	25.001	14.224	31.118	19.687	14.225	13.018	24.248	19.508	25.001	13.603	12.680	17.359	16.564	17.982	15.366	14.374
556574	25.001	14.230	30.997	19.670	14.205	13.030	24.551	19.474	25.001	13.608	12.683	17.336	16.555	17.967	15.375	14.388
556594	25.001	14.226	30.861	19.693	14.209	13.069	24.586	19.434	25.001	13.616	12.686	17.347	16.567	17.968	15.452	14.386
556614	25.001	14.231	30.865	19.725	14.168	13.044	24.516	19.407	25.001	13.624	12.686	17.336	16.603	17.992	15.355	14.400
556634	25.001	14.235	30.903	19.756	14.170	13.057	24.462	19.401	25.001	13.629	12.688	17.306	16.651	18.005	15.381	14.419
556654	25.001	14.236	30.973	19.764	14.173	13.095	24.481	19.403	25.001	13.637	12.689	17.301	16.687	18.009	15.432	14.434
556674	25.001	14.243	31.042	19.772	14.159	13.142	24.524	19.384	25.001	13.638	12.693	17.307	16.715	18.019	15.305	14.462
556694	25.001	14.241	31.127	19.793	14.160	13.180	24.667	19.422	25.001	13.644	12.688	17.296	16.719	18.021	15.360	14.485
556714	25.001	14.236	31.238	19.793	14.197	13.213	24.822	19.465	25.001	13.651	12.697	17.291	16.717	18.038	15.404	14.491
556734	25.001	14.238	31.346	19.788	14.214	13.214	24.882	19.476	25.001	13.665	12.702	17.300	16.729	18.012	15.313	14.510
556754	25.001	14.246	31.518	19.798	14.199	13.204	24.892	19.518	25.001	13.684	12.710	17.319	16.747	18.011	15.390	14.525
556774	25.001	14.252	31.603	19.814	14.162	13.189	24.770	19.535	25.001	13.697	12.713	17.325	16.760	18.037	15.415	14.550
556794	25.001	14.258	31.680	19.825	14.265	13.202	24.842	19.545	25.001	13.717	12.723	17.345	16.757	18.076	15.393	14.553
556814	25.001	14.271	31.694	19.875	14.386	13.208	24.708	19.490	25.001	13.750	12.733	17.378	16.715	18.087	15.456	14.537
556834	25.001	14.275	31.714	19.914	14.440	13.225	24.520	19.502	25.001	13.779	12.730	17.417	16.648	18.119	15.418	14.518
556854	25.001	14.281	31.824	19.961	14.456	13.229	24.472	19.564	25.001	13.813	12.739	17.441	16.619	18.195	15.542	14.527
556874	25.001	14.306	31.906	19.992	14.456	13.277	24.622	19.586	25.001	13.831	12.753	17.464	16.623	18.213	15.682	14.536
556894	25.001	14.326	31.884	19.992	14.495	13.289	24.716	19.653	25.001	13.852	12.756	17.471	16.636	18.236	15.632	14.552
556914	25.001	14.352	31.898	19.984	14.529	13.255	24.669	19.694	25.001	13.871	12.767	17.479	16.630	18.274	15.830	14.557
556934	25.001	14.367	32.000	20.012	14.502	13.218	24.706	19.725	25.001	13.884	12.767	17.508	16.657	18.286	15.720	14.574
556954	25.001	14.377	32.088	19.985	14.529	13.215	24.806	19.740	25.001	13.897	12.770	17.544	16.677	18.315	15.854	14.594
556974	25.001	14.389	32.057	19.990	14.573	13.231	24.668	19.743	25.001	13.920	12.771	17.577	16.657	18.378	15.448	14.595
556994	25.001	14.381	32.163	19.980	14.569	13.263	24.677	19.730	25.001	13.905	12.761	17.565	16.690	18.359	15.001	14.592
557014	25.001	14.345	32.039	19.846	14.485	13.281	24.712	19.708	25.001	13.865	12.751	17.476	16.774	18.342	14.678	14.623
557034	25.001	14.302	31.728	19.668	14.454	13.296	24.847	19.588	25.001	13.828	12.740	17.345	16.842	18.245	14.498	14.643
557054	25.001	14.252	31.552	19.578	14.445	13.300	24.899	19.445	25.001	13.792	12.730	17.241	16.915	18.102	14.433	14.670
557074	25.001	14.221	31.405	19.549	14.491	13.312	25.001	19.355	25.001	13.778	12.740	17.133	16.945	17.986	14.324	14.702
557094	25.001	14.196	31.220	19.552	14.556	13.307	25.078	19.276	25.001	13.769	12.751	17.051	16.967	17.898	14.297	14.735
557114	25.001	14.185	31.157	19.590	14.586	13.313	25.123	19.242	25.001	13.774	12.757	17.002	16.997	17.824	14.350	14.749
557134	25.001	14.184	31.254	19.602	14.662	13.318	25.151	19.263	25.001	13.788	12.747	17.003	16.987	17.777	14.358	14.721
557154	25.001	14.191	31.369	19.634	14.815	13.326	25.038	19.313	25.001	13.804	12.753	17.037	16.958	17.787	14.458	14.679
557174	25.001	14.210	31.438	19.651	14.945	13.320	24.894	19.405	25.001	13.822	12.756	17.084	16.923	17.832	14.547	14.646
557194	25.001	14.226	31.483	19.673	15.058	13.318	24.946	19.494	25.001	13.839	12.753	17.141	16.910	17.857	14.670	14.649
557214	25.001	14.242	31.451	19.702	15.069	13.332	25.078	19.518	25.001	13.850	12.761	17.198	16.913	17.865	14.776	14.655
557234	25.001	14.254	31.379	19.702	15.080	13.316	25.044	19.530	25.001	13.849	12.764	17.229	16.916	17.846	14.706	14.669
557254	25.001	14.273	31.290	19.677	15.113	13.300	24.972	19.533	25.001	13.846	12.766	17.173	16.926	17.819	14.627	14.674
557274	25.001	14.286	31.152	19.669	15.134	13.298	24.899	19.553	25.001	13.839	12.762	17.133	16.922	17.791	14.569	14.662
557294	25.001	14.281	31.008	19.696	15.107	13.301	24.858	19.497	25.001	13.835	12.757	17.143	16.947	17.755	14.619	14.650

557314	25.001	14.280	31.032	19.719	15.147	13.280	24.731	19.485	25.001	13.842	12.753	17.132	16.938	17.743	14.683	14.647
557334	25.001	14.290	31.151	19.749	15.192	13.268	24.553	19.526	25.001	13.860	12.757	17.117	16.888	17.715	14.656	14.648
557354	25.001	14.307	31.286	19.773	15.239	13.262	24.425	19.544	25.001	13.893	12.755	17.104	16.853	17.698	14.695	14.694
557374	25.001	14.328	31.392	19.773	15.307	13.273	24.457	19.559	25.001	13.933	12.772	17.122	16.849	17.697	14.627	14.749
557394	25.001	14.356	31.605	19.848	15.329	13.280	24.569	19.601	25.001	13.945	12.774	17.118	16.868	17.756	14.782	14.762
557414	25.001	14.379	31.721	19.886	15.325	13.274	24.724	19.631	25.001	13.946	12.774	17.164	16.900	17.798	14.849	14.780
557434	25.001	14.397	31.693	19.858	15.340	13.285	24.888	19.655	25.001	13.934	12.780	17.176	16.951	17.812	14.942	14.794
557454	25.001	14.407	31.572	19.778	15.398	13.279	25.106	19.653	25.001	13.929	12.785	17.196	16.987	17.821	14.975	14.797
557474	25.001	14.416	31.508	19.729	15.473	13.250	25.202	19.661	25.001	13.925	12.779	17.198	17.030	17.822	14.981	14.807
557494	25.001	14.424	31.526	19.692	15.433	13.232	25.240	19.676	25.001	13.918	12.782	17.183	17.063	17.828	14.976	14.840
557514	25.001	14.418	31.502	19.619	15.345	13.218	25.219	19.689	25.001	13.909	12.780	17.117	17.099	17.809	14.913	14.874
557534	25.001	14.392	31.443	19.577	15.283	13.223	25.256	19.634	25.001	13.894	12.783	17.033	17.153	17.721	14.980	14.918
557554	25.001	14.382	31.428	19.563	15.241	13.234	25.311	19.529	25.001	13.878	12.783	16.944	17.198	17.642	14.943	14.953
557574	25.001	14.375	31.305	19.520	15.246	13.233	25.419	19.395	25.001	13.872	12.792	16.865	17.264	17.578	14.877	14.990
557594	25.001	14.359	31.141	19.496	15.241	13.253	25.538	19.278	25.001	13.878	12.798	16.805	17.311	17.509	14.885	15.021
557614	25.001	14.350	30.915	19.413	15.253	13.258	25.580	19.199	25.001	13.878	12.810	16.767	17.338	17.445	14.823	15.046
557634	25.001	14.354	30.736	19.325	15.317	13.250	25.652	19.123	25.001	13.876	12.820	16.659	17.362	17.333	14.533	15.074
557654	25.001	14.379	30.477	19.207	15.576	13.256	25.760	19.024	25.001	13.899	12.848	16.482	17.402	17.133	14.410	15.110
557674	25.001	14.472	30.057	19.051	15.783	13.263	26.026	18.866	25.001	13.911	12.961	16.357	17.423	16.889	14.532	15.151
557694	25.001	14.579	29.553	18.911	16.002	13.273	26.460	18.717	25.001	13.929	13.114	16.265	17.416	16.685	14.363	15.185
557714	25.001	14.658	29.101	18.780	16.227	13.251	26.677	18.606	25.001	13.937	13.215	16.182	17.399	16.526	14.258	15.216
557734	25.001	14.714	28.741	18.673	16.439	13.263	26.916	18.493	25.001	13.952	13.291	16.114	17.406	16.380	14.420	15.254
557754	25.001	14.748	28.426	18.562	16.640	13.221	27.027	18.370	25.001	13.959	13.365	16.047	17.395	16.245	14.405	15.298
557774	25.001	14.769	28.179	18.451	16.746	13.144	27.169	18.250	25.001	13.957	13.454	15.986	17.406	16.103	14.480	15.385
557794	25.001	14.779	27.981	18.367	16.818	13.108	27.335	18.142	25.001	13.945	13.511	15.938	17.422	15.977	14.498	15.476
557814	25.001	14.782	27.793	18.294	16.846	13.082	27.584	18.058	25.001	13.949	13.537	15.893	17.444	15.872	14.526	15.524
557834	25.001	14.793	27.624	18.222	16.990	13.044	27.635	17.996	25.001	13.973	13.563	15.849	17.451	15.789	14.530	15.546
557854	25.001	14.806	27.441	18.132	17.130	12.946	27.584	17.902	25.001	13.988	13.600	15.800	17.459	15.691	14.513	15.571
557874	25.001	14.812	27.307	18.068	17.213	13.022	27.669	17.834	25.001	14.000	13.631	15.763	17.461	15.610	14.526	15.595
557894	25.001	14.811	27.184	17.997	17.281	13.023	27.694	17.767	25.001	14.001	13.659	15.718	17.479	15.523	14.496	15.612
557914	25.001	14.810	27.091	17.930	17.429	13.074	27.687	17.685	25.001	13.992	13.672	15.678	17.522	15.434	14.490	15.628
557934	25.001	14.812	26.987	17.855	17.549	13.079	27.721	17.629	25.001	13.999	13.697	15.648	17.542	15.358	14.318	15.666
557954	25.001	14.837	26.826	17.775	17.643	13.072	27.615	17.569	25.001	14.011	13.677	15.595	17.577	15.297	14.002	15.705
557974	25.001	14.859	26.685	17.708	17.711	13.071	27.706	17.513	25.001	13.992	13.633	15.547	17.590	15.238	13.922	15.732
557994	25.001	14.866	26.541	17.633	17.743	13.011	27.668	17.452	25.001	13.987	13.597	15.505	17.605	15.170	14.076	15.754
558014	25.001	14.872	26.392	17.581	17.822	13.010	27.664	17.395	25.001	13.997	13.612	15.469	17.620	15.106	14.317	15.762
558034	25.001	14.887	26.309	17.532	17.913	12.945	27.653	17.331	25.001	14.012	13.665	15.431	17.639	15.044	14.301	15.779
558054	25.001	14.910	26.226	17.455	17.884	12.859	27.810	17.252	25.001	14.026	13.718	15.396	17.653	14.967	14.396	15.801
558074	25.001	14.924	26.159	17.386	17.863	12.857	27.895	17.174	25.001	14.033	13.753	15.369	17.664	14.899	14.446	15.846
558094	25.001	14.942	26.079	17.312	17.844	12.829	27.932	17.102	25.001	14.037	13.784	15.344	17.691	14.840	14.450	15.884
558114	25.001	14.967	25.952	17.254	17.857	12.845	28.026	17.045	25.001	14.050	13.808	15.308	17.712	14.777	14.361	15.911
558134	25.001	14.986	25.867	17.220	17.866	12.870	28.137	17.007	25.001	14.070	13.822	15.276	17.719	14.723	14.537	15.936
558154	25.001	15.012	25.847	17.201	17.918	12.876	28.213	16.982	25.001	14.077	13.866	15.258	17.737	14.683	14.612	15.963
558174	25.001	15.028	25.898	17.170	18.023	12.876	28.174	16.942	25.001	14.072	13.870	15.250	17.784	14.634	14.613	15.990
558194	25.001	15.069	25.856	17.134	18.100	12.867	28.366	16.900	25.001	14.075	13.881	15.230	17.812	14.577	14.308	16.020
558214	25.001	15.132	25.807	17.037	17.868	12.852	28.408	16.851	25.001	14.042	13.861	15.186	17.820	14.534	14.511	16.030
558234	25.001	15.190	25.808	16.898	17.503	12.831	28.618	16.784	25.001	14.002	13.841	15.125	17.821	14.468	14.615	16.048
558254	25.001	15.237	25.850	16.781	17.170	12.801	28.912	16.723	25.001	13.967	13.860	15.067	17.817	14.409	14.677	16.062
558274	25.001	15.276	25.870	16.683	16.891	12.747	29.079	16.658	25.001	13.955	13.884	15.034	17.795	14.345	14.755	16.101
558294	25.001	15.320	25.859	16.580	16.674	12.740	29.096	16.605	25.001	13.942	13.936	14.992	17.750	14.296	14.735	16.190
558314	25.001	15.383	25.821	16.524	16.596	12.326	29.240	16.564	25.001	13.937	13.968	14.951	17.735	14.255	14.536	16.267
558334	25.001	15.442	25.730	16.460	16.631	12.421	29.368	16.489	25.001	13.924	14.003	14.916	17.759	14.212	14.381	16.317
558354	25.001	15.483	25.668	16.397	16.582	12.528	29.305	16.438	25.001	13.916	14.040	14.894	17.767	14.170	14.394	16.339
558374	25.001	15.519	25.639	16.354	16.475	12.438	29.268	16.403	25.001	13.914	14.076	14.881	17.777	14.145	14.530	16.347
558394	25.001	15.575	25.591	16.299	16.323	12.580	29.312	16.358	25.001	13.920	14.106	14.856	17.799	14.092	14.476	16.348
558414	25.001	15.626	25.520	16.252	16.217	12.645	29.395	16.313	25.001	13.909	14.142	14.838	17.826	14.049	14.502	16.350
558434	25.001	15.642	25.408	16.199	16.199	12.728	29.349	16.260	25.001	13.901	14.182	14.807	17.840	14.011	14.214	16.363
558454	25.001	15.647	25.239	16.157	16.451	12.807	29.182	16.215	25.001	13.902	14.218	14.771	17.863	13.971	13.926	16.379
558474	25.001	15.639	25.005	16.122	16.600	12.915	28.943	16.174	25.001	13.896	14.234	14.731	17.853	13.934	13.944	16.397
558494	25.001	15.621	24.824	16.108	16.730	13.022	28.887	16.146	25.001	13.936	14.266	14.717	17.850	13.900	14.219	16.413
558514	25.001	15.616	24.743	16.111	16.789	13.079	28.867	16.111	25.001	13.992	14.318	14.715	17.854	13.857	14.326	16.441

558534	25.001	15.632	24.709	16.116	16.825	13.069	29.077	16.091	25.001	14.021	14.369	14.712	17.850	13.825	14.378	16.473
558554	25.001	15.667	24.663	16.079	16.842	13.102	29.080	16.062	25.001	14.036	14.379	14.693	17.853	13.799	14.260	16.508
558574	25.001	15.707	24.718	15.992	16.524	13.156	29.194	16.016	25.001	13.995	14.355	14.663	17.845	13.754	14.559	16.535
558594	25.001	15.730	24.814	15.907	16.236	13.216	29.364	15.985	25.001	14.004	14.362	14.643	17.866	13.718	14.745	16.545
558614	25.001	15.730	24.833	15.856	16.005	13.216	29.378	15.974	25.001	14.043	14.407	14.615	17.856	13.697	15.118	16.591
558634	25.001	15.745	24.769	15.806	15.825	13.186	29.311	15.952	25.001	14.101	14.459	14.590	17.785	13.681	15.440	16.677
558654	25.001	15.762	24.761	15.753	15.667	13.029	29.264	15.922	25.001	14.161	14.500	14.558	17.693	13.662	15.451	16.746
558674	25.001	15.789	24.752	15.724	15.481	12.949	29.305	15.879	25.001	14.186	14.534	14.535	17.694	13.639	15.577	16.782
558694	25.001	15.825	24.765	15.663	15.326	12.722	29.358	15.837	25.001	14.202	14.570	14.509	17.705	13.614	15.253	16.835
558714	25.001	15.879	24.817	15.592	15.201	12.680	29.446	15.792	25.001	14.206	14.590	14.484	17.721	13.586	15.267	16.894
558734	25.001	15.927	24.817	15.552	15.093	12.728	29.563	15.769	25.001	14.216	14.613	14.462	17.724	13.564	15.003	16.963
558754	25.001	15.944	24.733	15.521	14.981	12.859	29.583	15.751	25.001	14.225	14.659	14.449	17.728	13.543	15.232	17.025
558774	25.001	15.967	24.700	15.484	14.870	12.871	29.575	15.709	25.001	14.234	14.697	14.437	17.711	13.525	15.402	17.081
558794	25.001	15.967	24.747	15.441	14.773	12.949	29.646	15.684	25.001	14.247	14.709	14.426	17.724	13.515	15.283	17.150
558814	25.001	15.967	24.779	15.399	14.693	12.936	29.718	15.648	25.001	14.250	14.745	14.416	17.707	13.489	15.229	17.191
558834	25.001	15.976	24.851	15.357	14.633	13.124	29.748	15.618	25.001	14.246	14.753	14.405	17.667	13.469	15.215	17.230
558854	25.001	15.972	24.888	15.320	14.567	13.132	29.719	15.586	25.001	14.206	14.780	14.393	17.618	13.449	15.254	17.273
558874	25.001	15.968	24.937	15.290	14.500	13.150	29.764	15.558	25.001	14.199	14.806	14.381	17.608	13.421	15.240	17.327
558894	25.001	15.952	24.984	15.264	14.446	13.170	29.769	15.537	25.001	14.201	14.840	14.372	17.607	13.402	15.256	17.418
558914	25.001	15.954	24.933	15.253	14.446	13.223	29.723	15.516	25.001	14.183	14.883	14.360	17.628	13.391	14.759	17.493
558934	25.001	15.938	24.735	15.260	14.780	13.237	29.121	15.479	25.001	14.190	14.895	14.360	17.671	13.362	14.806	17.535
558954	25.001	15.838	24.671	15.286	14.859	13.252	28.894	15.465	25.001	14.218	14.796	14.398	17.719	13.349	14.607	17.517
558974	25.001	15.657	24.719	15.397	14.843	13.303	28.618	15.524	25.001	14.231	14.632	14.459	17.763	13.419	14.745	17.377
558994	25.001	15.496	24.754	15.454	14.853	13.254	28.516	15.568	25.001	14.230	14.501	14.515	17.827	13.515	14.539	17.229
559014	25.001	15.341	24.741	15.461	14.835	13.277	28.483	15.579	25.001	14.214	14.419	14.468	17.897	13.551	14.200	17.182
559034	25.001	15.251	24.668	15.431	14.911	13.269	28.407	15.570	25.001	14.220	14.375	14.417	17.955	13.480	14.120	17.209
559054	25.001	15.257	24.370	15.345	15.190	13.269	28.404	15.475	25.001	14.211	14.388	14.433	17.960	13.391	14.069	17.261
559074	25.001	15.272	24.110	15.271	15.484	13.399	28.300	15.387	25.001	14.208	14.355	14.445	17.945	13.308	13.914	17.318
559094	25.001	15.259	23.915	15.211	15.665	13.400	28.162	15.311	25.001	14.195	14.318	14.430	17.931	13.243	13.970	17.342
559114	25.001	15.244	23.754	15.166	15.806	13.393	28.145	15.253	25.001	14.188	14.297	14.410	17.928	13.188	13.832	17.366
559134	25.001	15.225	23.623	15.119	15.993	13.374	28.140	15.198	25.001	14.171	14.284	14.400	17.937	13.139	13.871	17.403
559154	25.001	15?344	23.452	15.082	16.182	13.351	28.410	15.158	25.001	14.171	14.395	14.385	17.959	13.107	14.182	17.428
559174	25.001	15.295	23.305	15.059	16.232	13.351	28.457	15.134	25.001	14.176	14.490	14.336	17.963	13.086	14.148	17.401
559194	25.001	15.317	23.215	15.017	16.193	13.372	28.349	15.105	25.001	14.136	14.526	14.284	17.935	13.058	14.285	17.387
559214	25.001	15.324	23.137	14.984	16.248	13.373	28.242	15.074	25.001	14.109	14.573	14.242	17.902	13.028	14.234	17.391
559234	25.001	15.356	23.046	14.962	16.308	13.357	28.270	15.047	25.001	14.093	14.613	14.210	17.882	12.997	14.210	17.375
559254	25.001	15.382	22.949	14.935	16.364	13.353	28.268	15.018	25.001	14.075	14.642	14.179	17.860	12.981	14.192	17.335
559274	25.001	15.407	22.861	14.919	16.429	13.378	28.146	14.988	25.001	14.081	14.661	14.159	17.859	12.958	14.197	17.289
559294	25.001	15.421	22.764	14.897	16.494	13.300	28.083	14.955	25.001	14.092	14.679	14.136	17.850	12.935	14.253	17.271
559314	25.001	15.435	22.664	14.877	16.561	13.304	28.012	14.924	25.001	14.102	14.697	14.120	17.826	12.918	14.364	17.288
559334	25.001	15.468	22.580	14.851	16.538	13.312	27.919	14.892	25.001	14.113	14.707	14.105	17.830	12.894	14.359	17.306
559354	25.001	15.478	22.574	14.826	16.380	13.297	27.978	14.869	25.001	14.110	14.715	14.097	17.840	12.880	14.371	17.318
559374	25.001	15.476	22.581	14.816	16.477	13.276	27.918	14.839	25.001	14.132	14.746	14.109	17.853	12.864	14.476	17.329
559394	25.001	15.397	22.747	14.853	16.398	13.277	27.765	14.856	25.001	14.173	14.684	14.172	17.888	12.881	14.425	17.361
559414	25.001	15.271	22.953	14.974	16.260	13.299	27.615	14.945	25.001	14.190	14.581	14.252	17.931	12.967	14.663	17.364
559434	25.001	15.169	23.182	15.079	16.135	13.316	27.596	15.037	25.001	14.209	14.509	14.337	17.979	13.082	14.954	17.332
559454	25.001	15.106	23.411	15.178	15.999	13.340	27.485	15.136	25.001	14.231	14.454	14.428	18.029	13.204	15.130	17.316
559474	25.001	15.070	23.657	15.278	15.896	13.244	27.423	15.225	25.001	14.248	14.408	14.488	18.086	13.316	15.175	17.334
559494	25.001	15.042	23.824	15.366	15.790	13.307	27.397	15.307	25.001	14.267	14.383	14.546	18.112	13.414	15.351	17.348
559514	25.001	15.032	23.953	15.459	15.704	13.394	27.421	15.393	25.001	14.284	14.370	14.605	18.137	13.497	15.368	17.369
559534	25.001	15.041	24.108	15.534	15.642	13.395	27.492	15.470	25.001	14.303	14.358	14.664	18.154	13.577	15.359	17.392
559554	25.001	15.045	24.247	15.606	15.572	13.385	27.479	15.539	25.001	14.311	14.340	14.705	18.177	13.648	15.264	17.401
559574	25.001	15.042	24.363	15.662	15.572	13.375	27.401	15.616	25.001	14.325	14.319	14.740	18.206	13.715	15.371	17.391
559594	25.001	15.045	24.459	15.738	15.765	13.358	27.334	15.701	25.001	14.349	14.331	14.772	18.207	13.785	15.393	17.371
559614	25.001	15.062	24.681	15.830	15.920	13.360	27.128	15.759	25.001	14.389	14.313	14.805	18.164	13.844	15.342	17.365
559634	25.001	15.075	24.862	15.914	16.064	13.361	26.850	15.831	25.001	14.413	14.296	14.850	18.127	13.888	15.287	17.350
559654	25.001	15.092	25.004	16.016	16.129	13.328	26.667	15.894	25.001	14.437	14.279	14.899	18.059	13.931	15.372	17.368
559674	25.001	15.113	25.157	16.106	16.128	13.402	26.639	15.962	25.001	14.479	14.268	14.952	17.983	13.999	15.622	17.486
559694	25.001	15.121	25.325	16.122	16.104	13.405	26.701	16.015	25.001	14.512	14.265	14.979	17.981	14.070	15.665	17.582
559714	25.001	15.191	25.241	15.988	15.956	13.394	26.808	15.925	25.001	14.504	14.326	14.873	18.048	14.015	15.227	17.620
559734	25.001	15.310	24.896	15.853	16.042	13.377	26.970	15.805	25.001	14.498	14.451	14.790	18.121	13.894	15.235	17.668

559754	25.001	15.395	24.550	15.736	16.237	13.366	27.178	15.664	25.001	14.478	14.543	14.755	18.177	13.766	14.937	17.721
559774	25.001	15.449	24.245	15.650	16.448	13.346	27.381	15.552	25.001	14.469	14.595	14.724	18.206	13.670	14.897	17.785
559794	25.001	15.489	23.992	15.585	16.602	13.357	27.517	15.463	25.001	14.458	14.637	14.711	18.223	13.582	14.829	17.839
559814	25.001	15.502	23.815	15.529	16.639	13.354	27.564	15.396	25.001	14.459	14.652	14.698	18.231	13.524	14.753	17.892
559834	25.001	15.512	23.661	15.484	16.877	13.334	27.568	15.336	25.001	14.462	14.666	14.677	18.238	13.475	14.776	17.923
559854	25.001	15.512	23.552	15.440	17.081	13.332	27.614	15.285	25.001	14.470	14.674	14.657	18.271	13.427	14.701	17.965
559874	25.001	15.501	23.468	15.404	17.195	13.319	27.734	15.233	25.001	14.467	14.682	14.629	18.278	13.378	14.686	17.990
559894	25.001	15.491	23.370	15.367	17.298	13.326	27.882	15.179	25.001	14.470	14.683	14.610	18.298	13.334	14.689	18.028
559914	25.001	15.476	23.242	15.331	17.316	13.288	27.991	15.128	25.001	14.460	14.687	14.596	18.320	13.289	14.641	18.055
559934	25.001	15.463	23.116	15.293	17.444	13.274	27.996	15.075	25.001	14.451	14.687	14.600	18.353	13.254	14.610	18.097
559954	25.001	15.453	23.010	15.275	17.573	13.254	28.038	15.040	25.001	14.448	14.690	14.616	18.388	13.230	14.600	18.140
559974	25.001	15.446	22.956	15.243	17.649	13.258	27.975	14.997	25.001	14.442	14.697	14.613	18.407	13.198	14.620	18.159
559994	25.001	15.457	22.916	15.207	17.778	13.193	27.882	14.967	25.001	14.450	14.713	14.615	18.433	13.174	14.803	18.170
560014	25.001	15.512	22.880	15.192	17.665	13.182	27.989	14.959	25.001	14.466	14.754	14.587	18.435	13.165	14.993	18.141
560034	25.001	15.570	23.006	15.168	17.318	13.160	28.106	14.960	25.001	14.463	14.764	14.559	18.428	13.155	15.539	18.118
560054	25.001	15.609	23.204	15.150	17.028	13.153	28.275	14.979	25.001	14.483	14.775	14.538	18.439	13.159	15.746	18.133
560074	25.001	15.630	23.314	15.129	16.761	13.141	28.438	14.970	25.001	14.509	14.826	14.515	18.438	13.161	15.833	18.142
560094	25.001	15.647	23.422	15.104	16.561	13.125	28.528	14.951	25.001	14.544	14.874	14.488	18.435	13.162	15.937	18.187
560114	25.001	15.653	23.515	15.074	16.393	13.172	28.636	14.928	25.001	14.569	14.913	14.470	18.443	13.160	16.137	18.254
560134	25.001	15.660	23.621	15.054	16.231	13.161	28.804	14.906	25.001	14.550	14.953	14.453	18.416	13.168	16.139	18.366
560154	25.001	15.677	23.661	15.038	16.121	13.180	28.802	14.882	25.001	14.546	15.002	14.448	18.395	13.165	16.190	18.478
560174	25.001	15.720	23.623	15.019	16.028	13.197	28.755	14.858	25.001	14.548	15.048	14.446	18.416	13.168	16.182	18.559
560194	25.001	15.774	23.557	15.003	15.928	13.198	28.782	14.837	25.001	14.544	15.062	14.439	18.433	13.165	16.068	18.609
560214	25.001	15.828	23.474	14.976	15.825	13.204	28.775	14.810	25.001	14.536	15.065	14.432	18.441	13.164	15.931	18.613
560234	25.001	15.861	23.406	14.956	15.740	13.215	28.667	14.784	25.001	14.532	15.050	14.429	18.456	13.151	15.897	18.592
560254	25.001	15.878	23.415	14.933	15.671	13.213	28.624	14.767	25.001	14.560	15.046	14.433	18.475	13.158	15.864	18.574
560274	25.001	15.902	23.385	14.904	15.540	13.224	28.682	14.750	25.001	14.553	15.039	14.423	18.485	13.153	15.972	18.565
560294	25.001	15.860	23.383	14.917	15.430	13.317	28.804	14.792	25.001	14.564	14.984	14.457	18.454	13.182	16.473	18.609
560314	25.001	15.742	23.567	15.054	15.397	13.305	28.699	14.930	25.001	14.632	14.905	14.587	18.358	13.305	16.956	18.621
560334	25.001	15.650	23.914	15.222	15.528	13.315	28.339	15.093	25.001	14.724	14.823	14.723	18.179	13.487	16.782	18.753
560354	25.001	15.572	24.187	15.369	15.591	13.315	28.056	15.220	25.001	14.790	14.737	14.839	18.019	13.627	16.426	18.865
560374	25.001	15.495	24.367	15.484	15.629	13.310	27.789	15.319	25.001	14.855	14.668	14.945	17.898	13.754	16.641	18.733
560394	25.001	15.439	24.578	15.593	15.651	13.308	27.667	15.410	25.001	14.916	14.610	15.028	17.902	13.861	16.648	18.579
560414	25.001	15.415	24.865	15.700	15.689	13.303	27.511	15.513	25.001	14.961	14.575	15.079	17.930	13.966	16.603	18.521
560434	25.001	15.399	25.001	15.816	15.708	13.313	27.249	15.592	25.001	14.993	14.555	15.125	17.894	14.055	16.439	18.504
560454	25.001	15.386	25.116	15.916	15.774	13.359	27.059	15.658	25.001	15.010	14.541	15.176	17.913	14.120	16.375	18.425
560474	25.001	15.377	25.138	15.999	15.866	13.365	26.741	15.701	25.001	15.015	14.517	15.204	17.915	14.171	16.612	18.382
560494	25.001	15.362	25.167	16.065	15.940	13.344	26.576	15.759	25.001	15.033	14.509	15.215	17.954	14.224	16.281	18.446
560514	25.001	15.342	25.165	16.084	15.934	13.325	26.553	15.797	25.001	15.039	14.490	15.234	17.996	14.278	16.294	18.410
560534	25.001	15.330	25.101	16.132	15.944	13.396	26.681	15.844	25.001	15.022	14.474	15.248	18.067	14.325	16.304	18.345
560554	25.001	15.319	25.108	16.192	16.005	13.397	26.805	15.883	25.001	15.008	14.471	15.261	18.117	14.364	16.168	18.308
560574	25.001	15.320	25.045	16.196	16.050	13.367	26.855	15.919	25.001	14.998	14.470	15.279	18.151	14.407	16.033	18.276
560594	25.001	15.322	24.969	16.200	16.043	13.391	26.833	15.966	25.001	14.979	14.476	15.287	18.189	14.450	16.046	18.241
560614	25.001	15.312	24.928	16.224	15.943	13.387	26.798	16.002	25.001	14.972	14.477	15.307	18.228	14.493	16.099	18.244
560634	25.001	15.298	24.912	16.258	15.959	13.360	26.849	16.042	25.001	14.966	14.480	15.325	18.253	14.525	16.156	18.257
560654	25.001	15.306	24.959	16.287	15.921	13.346	26.859	16.096	25.001	14.971	14.489	15.344	18.285	14.555	16.188	18.279
560674	25.001	15.312	24.994	16.309	15.870	13.333	26.843	16.140	25.001	14.978	14.510	15.367	18.337	14.607	16.289	18.285
560694	25.001	15.324	25.078	16.342	15.864	13.365	26.712	16.204	25.001	14.989	14.525	15.378	18.388	14.652	16.292	18.297
560714	25.001	15.331	25.178	16.397	15.863	13.341	26.605	16.239	25.001	14.982	14.530	15.388	18.440	14.696	16.304	18.307
560734	25.001	15.328	25.227	16.443	15.989	13.335	26.643	16.292	25.001	14.991	14.534	15.405	18.469	14.740	16.395	18.319
560754	25.001	15.328	25.180	16.494	16.085	13.327	26.659	16.324	25.001	15.005	14.538	15.445	18.466	14.789	16.446	18.278
560774	25.001	15.335	25.204	16.558	16.128	13.303	26.688	16.365	25.001	15.017	14.533	15.486	18.426	14.828	16.470	18.212
560794	25.001	15.338	25.170	16.617	16.163	13.285	26.549	16.400	25.001	15.033	14.529	15.517	18.399	14.861	16.434	18.148
560814	25.001	15.342	25.129	16.677	16.140	13.293	26.314	16.437	25.001	15.036	14.519	15.553	18.388	14.904	16.570	18.089
560834	25.001	15.326	25.059	16.724	16.116	13.321	25.995	16.469	25.001	15.040	14.493	15.583	18.382	14.945	16.102	18.012
560854	25.001	15.310	25.058	16.766	16.111	13.324	25.682	16.510	25.001	15.046	14.460	15.604	18.305	14.992	16.209	17.936
560874	25.001	15.292	25.151	16.837	16.119	13.319	25.447	16.552	25.001	15.064	14.441	15.606	18.233	15.027	16.396	17.922
560894	25.001	15.283	25.246	16.897	16.112	13.363	25.332	16.580	25.001	15.093	14.431	15.621	18.150	15.059	16.701	17.918
560914	25.001	15.282	25.356	16.968	16.129	13.386	25.122	16.604	25.001	15.130	14.427	15.661	18.087	15.096	16.457	17.968

APPENDIX D PC-TRAN INPUTS

* Indicates input used in analysis

1. ATMOSPHERIC MODEL
   - A. Specify meteorological data
   - B. Tropical model atmosphere
   - C. Midlatitude summer
   - D. Midlatitude winter
   - E. Subartic summer
   - F. Subartic winter
   - G. 1962 U.S. standard
   - *H. Radiosonde data

2. TYPES OF ATMOSPHERIC PATH
   - A. Horizontal
   - *B. Vertical or slant path between two altitudes
   - C. Vertical or slant path to space

3. MODES OF EXECUTION
   - A. Transmittance mode
   - *B. Radiance mode

4. SPECIFY TEMPERATURE/PRESSURE ALTITUDE PROFILES TO BE USED
   - *A. Normal

5. SPECIFY WATER VAPOR ALTITUDE PROFILE USED
   - *A. Normal

6. OZONE PROFILE
   - *A. Normal
   - B. Tropical
   - C. Midlatitude summer
   - D. Midlatitude winter
   - E. Subartic summer
   - F. Subartic winter
   - G. 1962 U.S. standard atmosphere

7. SPECIFY NORMAL OPERATIONS OR RADIOSONDE DATA WILL BE USED EITHER INITIALLY OR ON SUBSEQUENT RUNS
   - A. Normal
   - *B. Radiosonde

8. SPECIFY NORMAL OPERATIONS OR SUPPRESS PRINTING
   - *A. Normal
   - B. Suppress printing

9. TEMPERATURE OF THE EARTH AT THE LOCATION AT WHICH CALCULATION IS TO BE PERFORMED
   *A. (from data)

10. SPECIFY THE SURFACE ALBEDO OF THE EARTH
   *A. Assume blackbody default

11. EXTINCTION TYPE
   A. No aerosol attenuation
   B. Rural extinction, 23 km VIS
   C. Rural extinction, 5 km VIS
   *D. Navy maritime
   E. Maritime, 23 km VIS
   F. Urban, 5 km VIS
   G. Troposphere, 50 km VIS
   H. User defined
   I. Fog 1, 0.2 km VIS
   J. Fog 2, 0.5 km VIS

12. SEASONAL DEPENDENCE OF PROFILES
   *A. Default to season of model
   B. Spring/summer
   C. Fall/winter

13. PROFILE AND EXTINCTION FOR STRATOSPHERIC AEROSOLS
   *A. Default to stratospheric background
   B. Stratospheric background
   C. Aged volcanic type/moderate volcanic profile
   D. Fresh volcanic type/high volcanic profile
   E. Aged volcanic type/high volcanic profile

14. SPECIFY AIR MASS CHARACTER
   A. Open ocean
   *B. 3
   .
   .
   .
   J. Strong continental influence

15. DETERMINE THE INCLUSION OF CIRRUS ATTENUATION
   *A. No cirrus
   B. Use cirrus profile

16. U.S. ARMY VERTICAL STRUCTURE ALGORITHM (not used)

17. SPECIFY METEOROLOGICAL RANGE (km) (default)

18. CURRENT WIND SPEED (from data)

19. 24 HOUR AVERAGE WIND SPEED (from data)

20. PRECIPITATION RATE (0 from data)

21. ATMOSPHERIC LEVELS
    *A. Initial altitude (0 at target)
    *B. Final altitude (0 at target)
    C. Initial zenith angle as measured from the initial altitude
    D. Path length

22. RADIUS OF THE EARTH
    A. Specify radius
    *B. Default (6371.23 km)

23. PROGRAM OPERATION
    *A. Normal program operation
    B. Select downward type two long path

24. SPECTRAL RANGE (corresponds to 8-12 μm band)
    *A. Initial frequency (833.0 cm^{-1})
    *B. Final frequency (1250 cm^{-1})
    *C. Frequency increment (5 cm^{-1})

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Thesis
W773 Wood
c.1 Thermistor validation
and path radiance effects
in ship thermal image
measurements.